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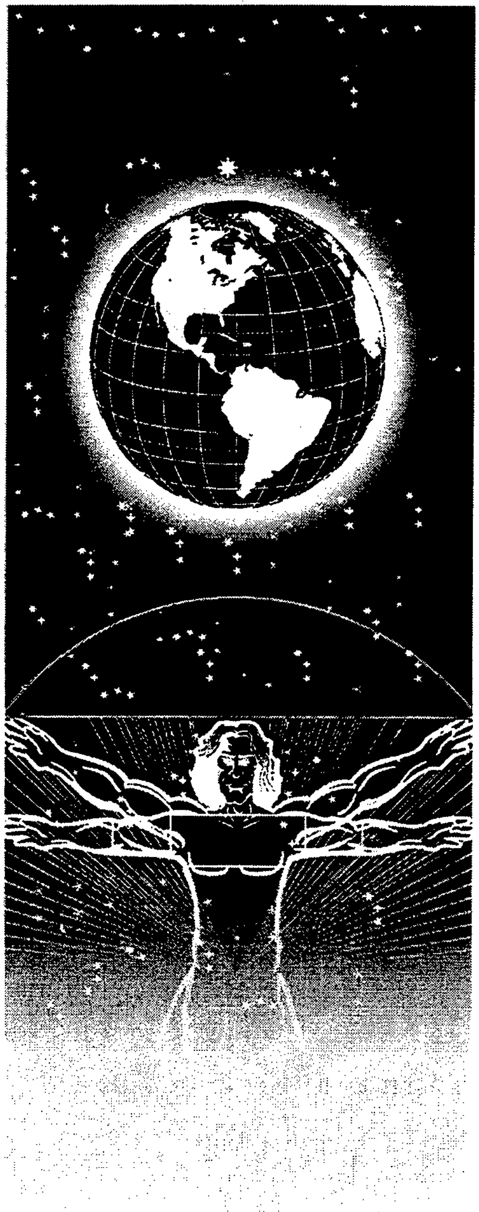

UNITED STATES AIR FORCE RESEARCH LABORATORY

M2DART: A REAL-IMAGE SIMULATOR VISUAL DISPLAY SYSTEM

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This report describes the Mobile Modular Display for Advanced Research and Training (M2DART) that was designed and fabricated at the Air Force Research Laboratory's Warfighter Training Research Division in Mesa, Arizona. The M2DART is an eight-channel, state-of-the-art, real-image, rear-projection, visual display system. It is a full-color, high-resolution, wraparound display system designed for use with single-seat cockpit simulators. This report provides a system description, which includes hardware configuration, screen geometry, field of view, spatial resolution, luminance, and contrast values.

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PREFACE

This report provides a technical description of the Mobile Modular Display for Advanced Research and Training (M2DART) Visual Display System, which was developed at the Air Force Research Laboratory (AFRL), Human Effectiveness Directorate, Warfighter Training Research Division (AFRL/HEA), in Mesa, AZ. The work was conducted under Work Unit 2743-B0-02, Warfighter Training Research, and USAF Contract F41624-97-D-5000. The Laboratory Contract Monitor was Mr Jay Carroll. The work was supported by Work Unit 2743-32-08, Visual Display Development; Laboratory Work Unit Monitor was Mr Philipp W. Peppler.

The authors would like to acknowledge individuals who contributed generously of their time and support to the successful implementation of the M2DART Visual Display System and this report. We would first like to thank Colonel Lynn A. Carroll, Major Reid Reasor, and Major Justine Good of AFRL/HEA. Maj Reasor provided the vital user input that was necessary to define the screen geometry during the initial system design process. Col Carroll, Maj Reasor, and Maj Good all contributed greatly of their time and management expertise to insure that laboratory and contractor personnel had access to necessary resources and data. Without their support, it would not have been possible to complete four operational M2DART Visual Display Systems within a relatively short time.

Mr Richard Olson, Lockheed Martin, worked closely with Mr Leonard Best, Raytheon Training and Services Inc, to iron out the myriad of details in the mechanical design of the M2DART. Mr Olson's engineering expertise and skills as a master craftsman gave the completed system its polished and professional appearance. We want to express our appreciation to Dr George Geri, Raytheon Training and Services Inc, for his work in providing contrast, luminance, and spatial resolution measurements. On several occasions, he has enlightened us on the theory and terminology for spatial resolution and the methods used to determine it. The AFRL/HEA fabrication group, comprised of Lockheed Martin, Boeing, and Raytheon personnel, worked many long days and nights to insure that all four systems were completed on schedule.

M2DART: A REAL-IMAGE SIMULATOR VISUAL DISPLAY SYSTEM

SUMMARY

This report describes the Mobile Modular Display for Advanced Research and Training (M2DART) that was designed and fabricated at the Air Force Research Laboratory's Warfighter Training Research Division (AFRL/HEA) in Mesa, AZ. The M2DART is an eight-channel, state-of-the-art, real-image, rear-projection, visual display system. It is a full-color, high resolution, wraparound display system designed for use with single-seat cockpit simulators. This report provides a system description, which includes hardware configuration, screen geometry, calculated spatial resolution, and field of view.

INTRODUCTION

This document describes the Mobile Modular Display for Advanced Research and Training (M2DART). The DART is a state-of-the-art, real-image, rear-projection, visual display system (Figure 1). The M2DART was engineered and developed at the Warfighter Training and Research Division of the U.S. Air Force Research Laboratory (AFRL) in Mesa, AZ. Raytheon Training and Services, Inc. is AFRL's prime contractor in Mesa, with Boeing and Lockheed Martin as subcontractors. Individuals from AFRL, Raytheon, Boeing, and Lockheed Martin participated as part of the M2DART Visual Display System engineering team.

Figure 1. M2DART Visual Display System Configured with Multitask Trainer (MTT) Cockpit

The design of the M2DART Visual Display System is a joint effort between AFRL and contractor personnel. The M2DART is part of AFRL's long-term development goal of producing a display and imaging system combination with significantly improved visual acuity in a full field-of-view/field-of-regard environment. The M2DART design is based on user input and experience gained from previous programs involving other rear-projected, real-image display systems developed at AFRL. The M2DART display system, and its predecessors, demonstrated that a rear-projected, real-image approach is a cost-effective means of providing high-resolution, high-brightness, full-color displays. The final design of the M2DART display system represents a balance between such considerations as training requirements, cost, number of available image generator (IG) channels, system resolution, field-of-view (FOV), brightness, image stability, and maintainability.

The basic system design was completed in April 1996 by AFRL visual engineering team. A subcontract was awarded to Coplin Manufacturing (Phoenix, AZ) for fabrication of the fiberglass covers. Coplin delivered four fiberglass covers to AFRL prior to March 1997. Four complete M2DART display systems were fabricated and operational by April 1997.

In April 1997, four M2DART visual display systems were deployed to the US Air Force 50th Anniversary Celebration in Las Vegas, NV. Upon arrival in Las Vegas, setup and integration of all four systems were completed within 72 hours. At the completion of the event, the four systems were relocated back to the AFRL/HEA facility in Mesa, AZ.

M2DART DESCRIPTION

The M2DART is a full field-of-regard, flight simulation display system for single-seat aircraft. It has a limited instantaneous field-of-view (FOV) that is used in conjunction with a head-tracking system and video router to provide the full field of regard. It has been designed to be independent of a specific visual IG or cockpit. The system currently utilizes standard, commercial, off-the-shelf (COTS) Barco cathode-ray tube (CRT) projectors to display out-the-window (OTW) visual imagery to the pilot. However, with some design modification, the M2DART will be capable of using advanced, ultra-high resolution, laser projectors when they become available. There are eight flat, rear-projection screens tiled together to create a 360° wraparound display. Horizontal FOV for each of the eight window screens varies between 72° and 82°. Vertical FOV encompasses an angle from approximately 42° downward to 90° upward. The screen normals are 36 inches from the design eyepoint. The forward screen is custom fitted to the contours of the system cockpit. The two rear screens, which are hinged and can be fully opened, allow ingress/egress to the system. The M2DART uses a real-image, rear- projection system, which provides higher luminance levels than typical collimated image systems.

Optimally, an eight-channel IG would provide imagery for a full field-of-regard display. Currently, an IG with six viewports, used in conjunction with a head-position tracker and video router, provides imagery to the windows being viewed by the pilot. The M2DART display system uses a Polhemus head-tracking system. Data from the head tracker is used as a reference for control of an 8 x 8 matrix video router. The router will switch the video from IG viewports to the window corresponding to the pilot's head position. The switching angles can be controlled by user-defined algorithms.

The M2DART display system was designed to be modular to facilitate transport and assembly. There are three towers used to house the projectors. One tower, positioned forward of the cockpit, holds five projectors (four out-the-window, and one head-up display (HUD) projector), while the two remaining towers, positioned aft of the cockpit, each contain two projectors. The two aft towers also provide support for the fiberglass cover. All projector towers are equipped with casters and leveling feet to facilitate transport and setup. The design of the rear-projection towers permits them to be transported in a lowered position, then raised telescopically (with gas-charged struts) and locked into position for normal operation. Projectors in the front tower are mounted on trolleys and hinged frames for positioning during system installation. During transport the projectors are retracted on the hinged frames. This reduces the overall space required for shipping.

The M2DART has the option of having two 19-inch monitors installed in back of the two rear towers. Figure 2 shows the position of monitors. These monitors are used as repeaters for an OTW visual scene, cockpit displays, or other user-selectable options. A seven-section, fiberglass cover reduces extraneous light, debris, and dust. Depending on facility limitations and customer requirements, the system design can be altered to provide for a different cover design. All modules are made to fit through a standard 6-foot double door.

Figure 2. Engineering Drawing of M2DART with Fiberglass Cover
Rear View

Projectors and Screens

The M2DART uses electromagnetically focused, Barco, CRT projectors. The projectors are individually controlled by an infrared (IR) remote control and an RS-232 port of a laptop computer. AFRL uses a laptop computer to download all vital projector setup parameters. Figure 3 depicts the position of the M2DART display's towers and upper fold mirrors.

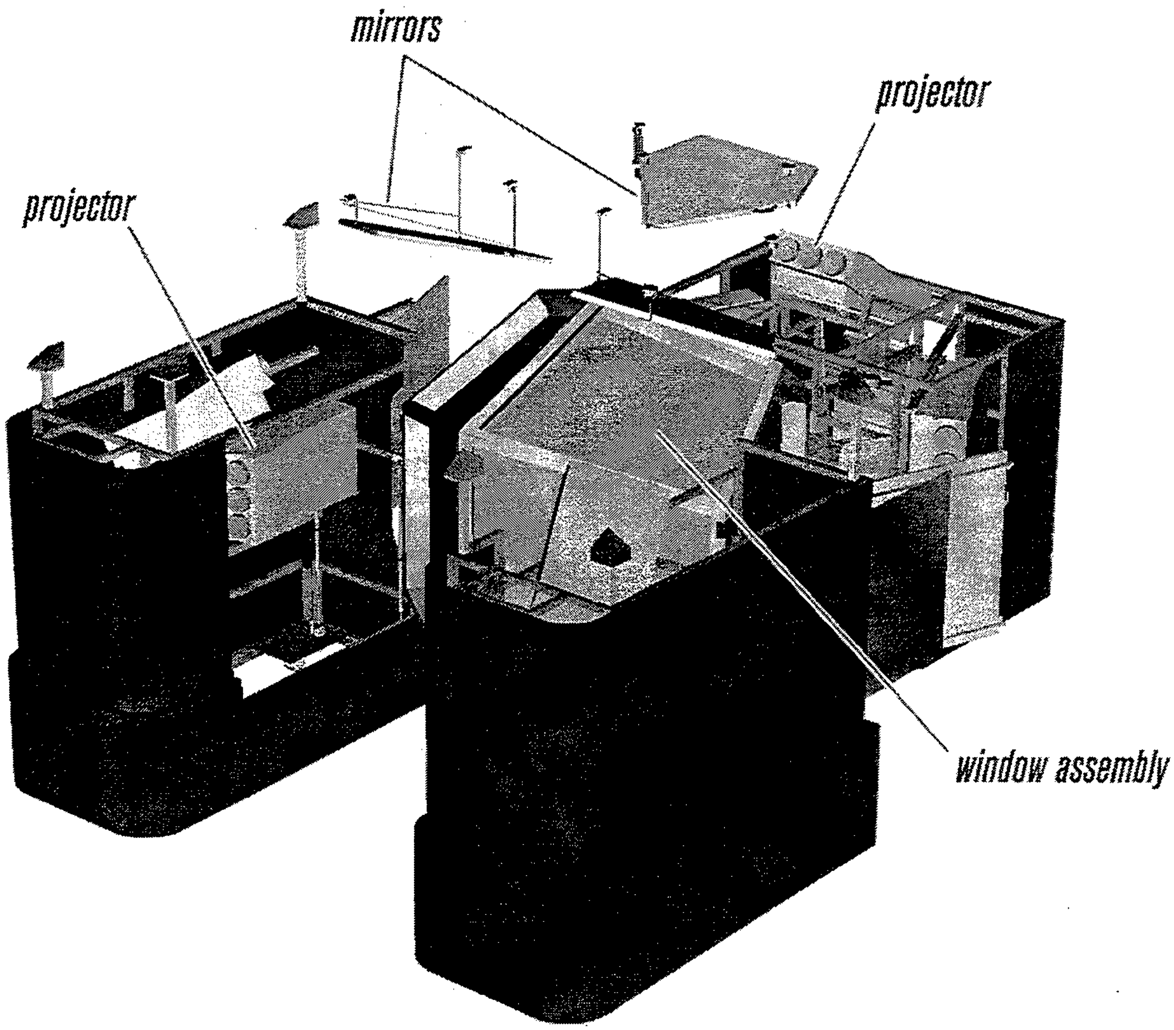

Figure 3. M2DART Display with Cover Removed
Showing Position of Towers and Upper Fold Mirrors

In the event of a critical module failure or replacement, the laptop computer can be used to quickly restore the original parameters for the projector setup. The display screen options are high contrast diffusion screens, on a 3/8-inch thick acrylic substrate with an average gain of 1.2; or fine pitch, fresnel/lenticular screens, with a horizontal viewing angle of 180° and an average gain of 4.0. Fold mirrors within the projected light path are used to reduce system size. They are fabricated from lightweight mylar film stretched over aluminum frames.

Screen Geometry

Figures 4-6 depict the M2DART's display screens. The M2DART's horizontal FOV is ±180°. Its vertical FOV is +90° and -41.9°. For most cockpits, this will cover virtually all of the visual FOV from the pilot's eyepoint. There are no vertical seams on the upper front window that would interfere with air refueling training operations. The two side screens have been extended towards the aft so as not to compromise the "3 and 9 o'clock" line of sight. The apex of the three upper windows is directly above the design eyepoint. As such, it is located in an area that will seldom be in the pilot's line of sight. The abutment of the two upper aft windows extends straight back. Again, this is a position that is not usually in the pilot's line of sight.

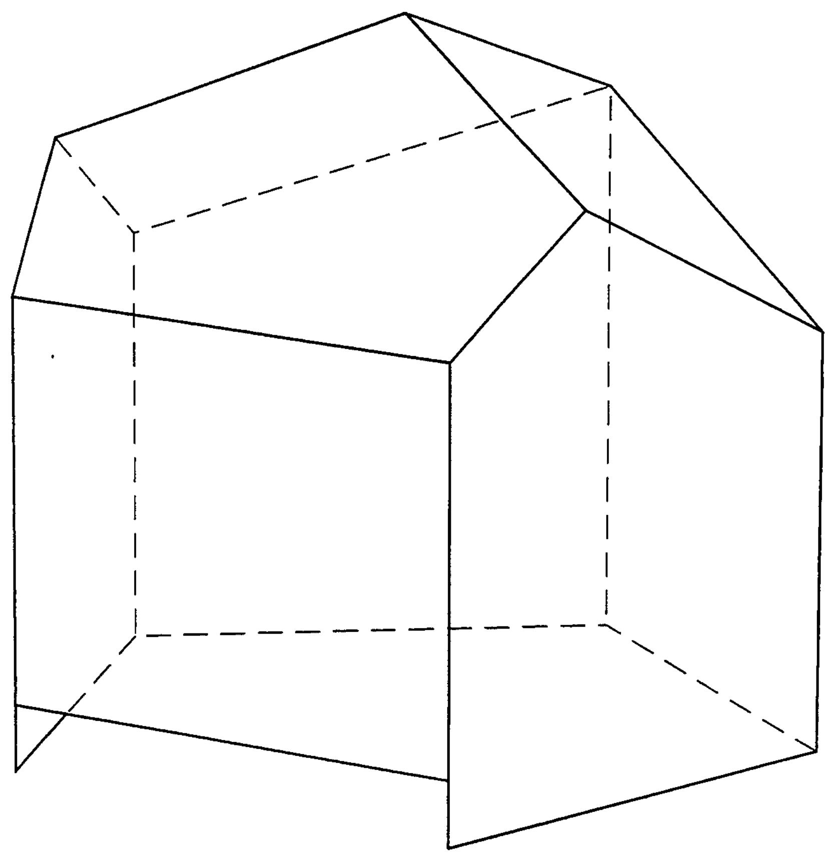

Figure 4. M2DART Display Screens
Front Perspective View

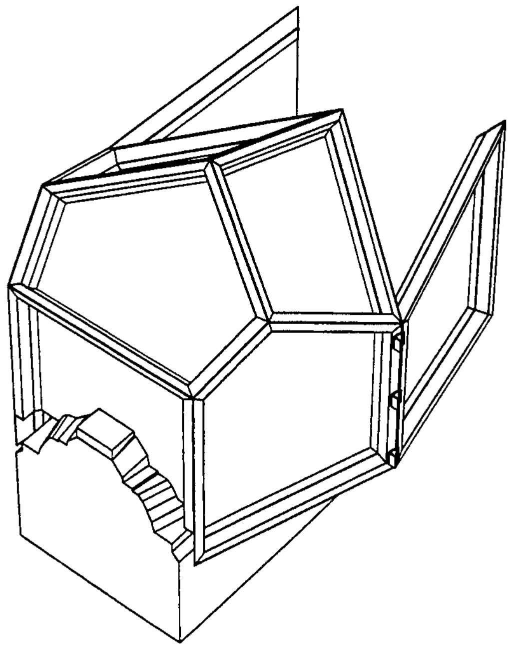

Figure 5. M2DART Display Screens
Front View With F-16 MTT Cockpit
Showing Cockpit Cutout and Open Access Doors

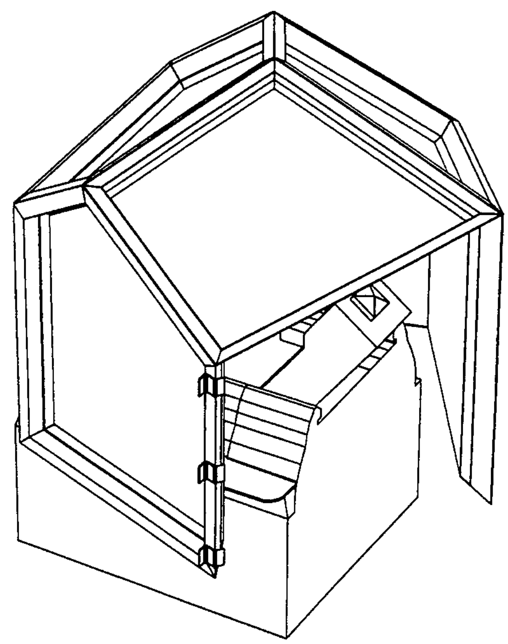

Figure 6. M2DART Display Screens
Left Rear View With F-16 MTT Cockpit
Showing Access Door Removed

The screen abutment angles range from 100.5° to 122.5°. Larger screen abutment angles tend to reduce visual distortion effects of moving objects in the visual scene as they transition between view screens. The front window has a relatively small surface area. This allows for a higher concentration of pixels in the area most often viewed by the pilot (Fig. 7). However, since pixel density affects apparent brightness, careful consideration was also given to balancing front window brightness with the adjoining windows. The contour of the front window can be cut to match most single-seat cockpit outlines. Viewing distance to each screen normal is 36 inches. Thus, a common screen normal distance for all eight display screens reduces the pilot's need to refocus when changing gaze direction.

Tables 1 and 2 contain additional M2DART specifications.

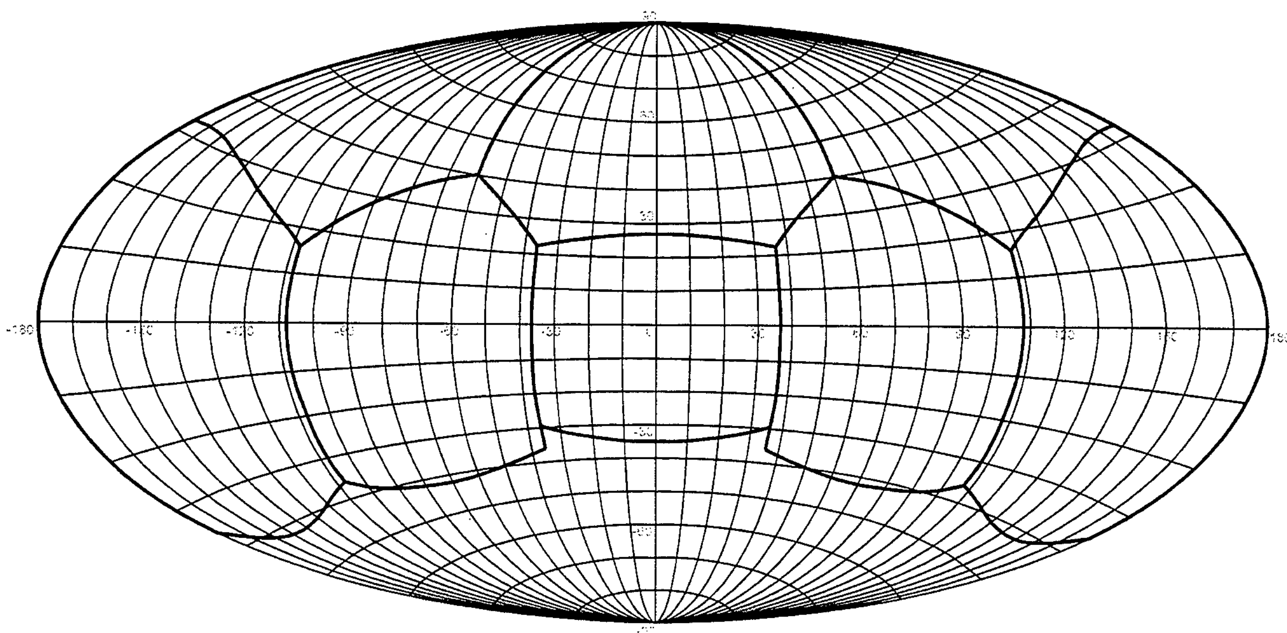

Figure 7. M2DART *Aitoff* Map Projection
With 0° Az/El Plotted from Design Eyepoint

Table 1. M2DART Calculated Spatial Resolution

Calculated Spatial Resolution at Different Video Rates					
Number of Display Windows	8	8	8	8	8
Video Rate					
# Horizontal pixels	1280	1600	1700	2048	5120
# Vertical lines	1024	1280	1350	2048	4096
Calculated Horizontal *(arcmin/pixel pair)**					
Best	6.8	5.4	5.1	4.2	1.7
Worst	7.8	6.2	5.8	4.9	1.9
Average	7.3	5.8	5.5	4.5	1.8
Calculated Vertical *(arcmin/line pair)*					
Best	7.2	5.8	5.5	3.6	1.8
Worst	8.4	6.7	6.4	4.2	2.1
Average	7.8	6.3	5.9	3.9	2.0

Table 2. M2DART Specifications

M2DART Specifications	
Number of Channels	8
Screen Dimensions	
Largest	
Horizontal (inches)	63.5
Vertical (inches)	52.3
Smallest (Front Window)	
Horizontal (inches)	52.3
Vertical (inches)	42.8
Field of View (in a channel)	
Largest	
Horizontal (degrees)	82.8
Vertical (degrees)	72.0
Smallest	
Horizontal (degrees)	72.0
Vertical (degrees)	61.5
Screen Abutment Angles	
Smallest (Degrees)	100.5
Largest (Degrees)	122.5
Viewing Distance to Screen *Normals (inches)*	36.0
Field of Regard	
Horizontal	360.0
Vertical	+90, -41.9

M2DART System Dimensions

Figures 8-10 portray the M2DART system dimensions and the display screen flat pattern layout.

Front Tower:	6' 10" H x 4' 8" W x 7' 6" L
Rear Towers:	9' 2" (7'9" lowered) H x 4' 2" W x 9' 1" L
System Footprint w/o Fiberglass Covering:	11' 9" H x 14' 8" W x 20' 5" L
System Footprint with Cover:	12' 3" H x 18'6" W x 26' 5" L

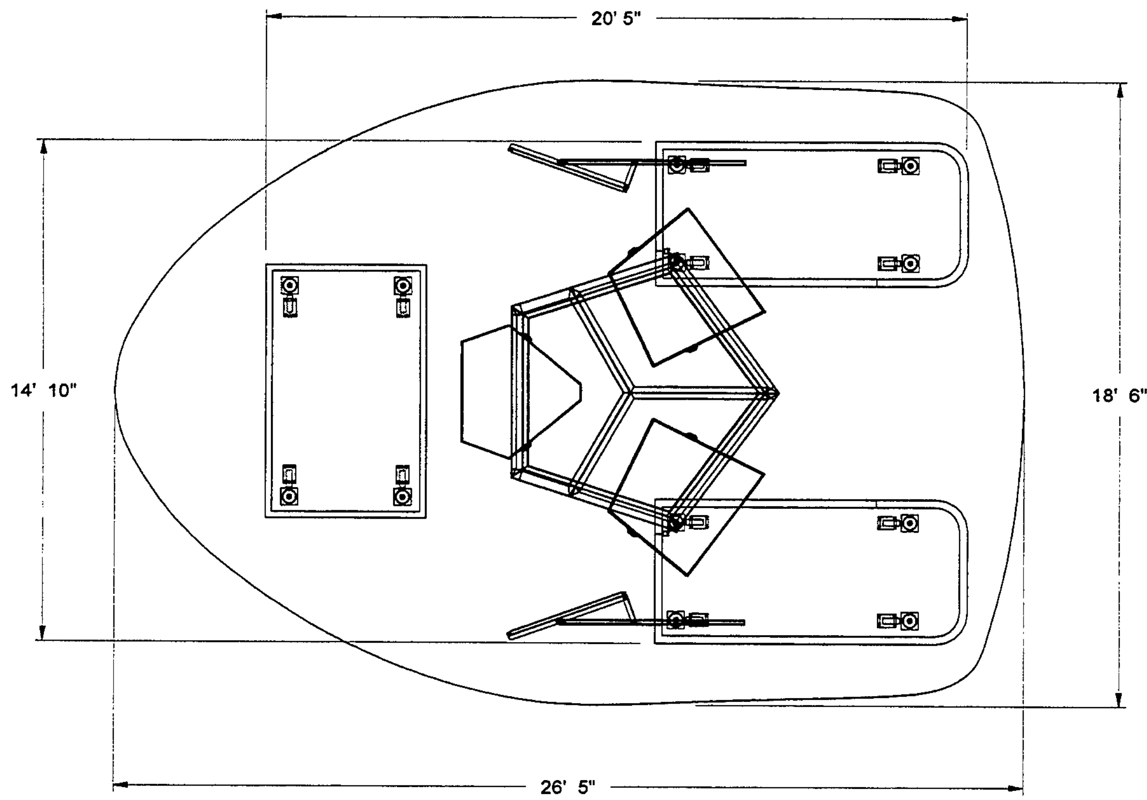

Figure 8. System Footprint

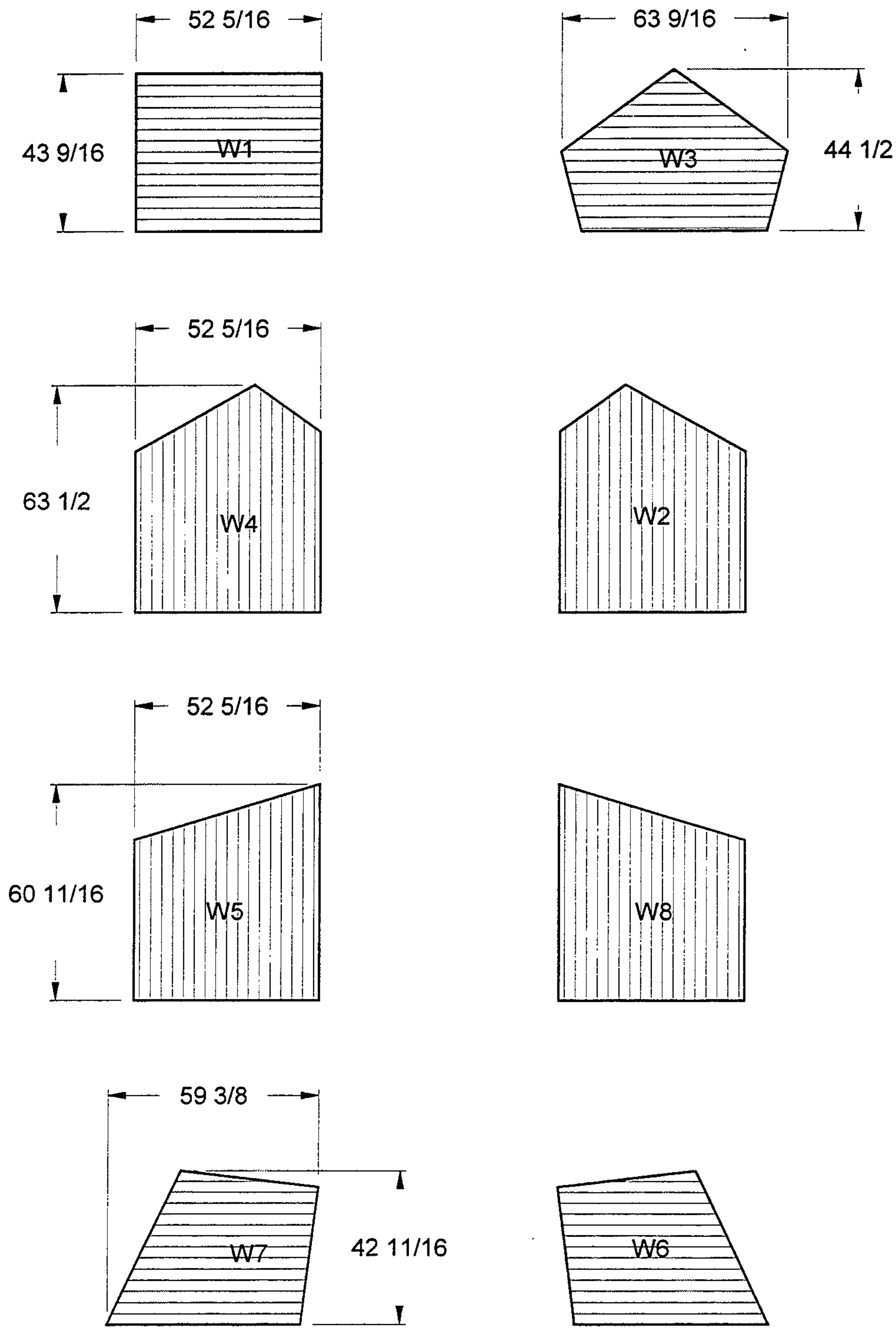

Figure 9. M2DART Display Screen Sizes and Scan Orientation

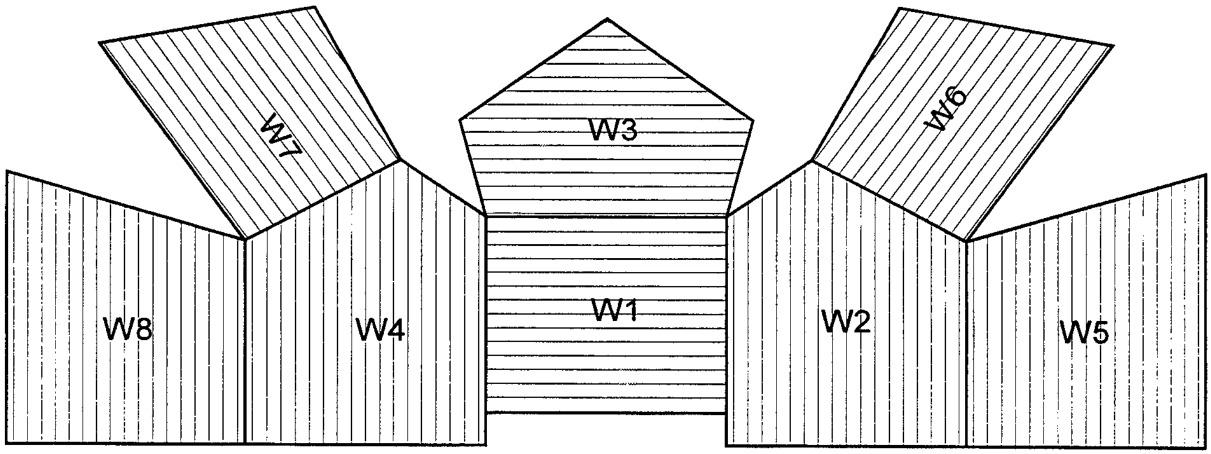

Figure 10. Display Screen Flat Pattern Layout

CONCLUSION

The M2DART Visual Display System design represents a compilation of user inputs and experience gained from previous programs at AFRL involving rear-screen projection technology. The M2DART Visual Display System demonstrates that real-image, rear-projected display systems provide a viable, cost-effective alternative for many training tasks, as compared to more expensive and complicated collimated display systems and front-projected domes.