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THE MULTI MODE MATRIX FLAT PANEL DISPLAY
–TECHNOLOGY AND APPLICATIONS

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THE MULTI-MODE MATRIX (MMM) FLAT PANEL DISPLAY

- TECHNOLOGY AND APPLICATIONS

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A B S T R A C T

An important aspect of current developments in advanced cockpit design is the introduction of a small number of interactive multi-function electronic displays with digital data processing, in conjunction with a MIL-STD-1553 type of multiplex data bus in an integrated system as opposed to the conventional approach of large numbers of stand-alone electro-mechanical instruments and a variety of different and independent dedicated inputs. This paper describes recent advances in high speed vector graphic display systems based on modular LED flat panel technology and micro-programmable multi-processor data handling with MIL-STD-1553B compatible interfaces. Applications and system performance are discussed in terms of typical military airborne mission-oriented display image formats and associated hardware and software characteristics. The real-time vector graphic presentations as described include flight control, navigation, communications, engine and fuel management, weapons management, symbolic map, signal communication and other types of real-time cockpit advisory information.

1.0 INTRODUCTION

Light emitting diodes (LEDs) have been used for years in aircraft crew stations in the form of relatively simple instrument signal indicators, status indicators and fixed format alphanumeric readouts. Full exploitation of the LEDs promising potential for relatively high resolution, large screen solid state cockpit displays however required major advances in high density circuit packaging and interconnect technology. In May 1975 the need for such advances was addressed in a jointly-funded USAF/Canadian Government contract let to Litton Systems Canada Limited for the development and construction of Multi-Mode Matrix (MMM) LED flat panel displays suitable for evaluation for ultimate use in the emerging new generation of military aircraft.

In December 1978, the first MMM Concept Demonstrator Display was delivered to the USAF Flight Dynamics Laboratory (AFFDL) at Wright Patterson Air Force Base. Design and performance characteristics of this display and the general rationale for the use of dot matrix displays in military cockpits has been discussed by Burnette and Melnick, reference 1, and reported on by Klass, reference 2.

From January 1979 to the present, development and construction of a series of four Advanced Development Model (ADM) MMM displays has continued under a jointly-funded Canadian Department of Industry, Trade and Commerce (DITC)/Litton Systems Canada Limited (LSL) contract. For this phase of the project, the AFFDL serves as technical adviser to DITC and also as the principal MMM display system evaluator.

Since its inception in 1975, the MMM display project has recorded substantial progress in the development of a versatile family of modular, medium resolution, LED flat panel displays which exhibit excellent legibility in "open cockpit" ambient illumination of 10,000 ft. candles (108,000 lux). In addition to the use of newly developed high efficienty LED array structures, high density interconnects and drive circuit ICs, the MMM displays employ multiprocessor data handling under software control to achieve high speed vector graphic capabilities. The system architecture, both hardware and software, is modular throughout, thereby permitting the same basic design to be employed for a wide range of display screen sizes and aircraft/ display interface configurations.

The present phase of the MMM project will yield display system hardware and software suitable for evaluation by potential end users. The four (4) ADM display systems presently under construction are:

MODEL	SCREEN SIZE	INTENDED USE	COMPLETION DATE
ADM I	12.5 cm x 10 cm	A-7 Simulator at WPAFB	November/1981
ADM II	7.5 cm x 7.5 cm	Flight Test	February/1982
ADM III	12.5 cm x 12.5 cm	Flight Test	January /1982
ADM IV	7.5 cm x 2.5	Simulator	October /1981

All of the above ADM displays will employ fully abutting 1 in. by 1 in. modules and yellow-green emitting LED arrays with a density of approximately 4000 LEDs per square inch (62.5 lines/inch). The imaging characteristic legibility and measurement criteria for this type of dot matrix display have been reported on by Burnette, reference 3, and the design concepts for the flight test displays are discussed by Burnette et al, in reference 4. ADM II and ADM III are being designed and packaged in accordance with MIL-E-5400 and will be safety-of-flight tested in accordance with MIL-STD-810 for both fixed-wing and helicopter applications.

The principle advantages of LED flat panel displays relative to conventional electromechanical instrumentation are considered to be:

- multi-purpose, flexible information formatting, eliminates large numbers of dedicated single purpose instruments and saves on panel sapce.
- fully compatible with present trends to integrated multiplex dual redundant systems.
- pilot/computer/display interactive facility enhances man/ machine communications and pilot efficiency.
- total solid state construction eliminates moving parts and enhances reliability, maintainability and useful service life.

Advantages of LED flat panel displays relative to CRTs (for vector graphic applications) are considered to be:

- shallow mounting depth
- relatively immune to catastrophic failures
- versatile screen size
- low distortion independent of screen size
- superior critical detail and image clarity
- sunlight viewable, independent of screen size
- discrete (digital) pixel address
- high update rate capability
- superior reliability and useful service life
- negligible hazards from high voltage, implosion or X-radiation

2.0 DISPLAY SURFACE DESIGN

A photograph of the ADM I display head is shown in Figure 2-1 and a simplified drawing of the LED module in Figure 2-2. Modules are mounted on a coldplate/heat exchanger and locked into very precise position by means of locating pins on the rear of each module as shown in Figure 2-2. Due to the high accuracy maintained in module position and in the position of each LED relative to the module alignment pins, the LED to LED pitch distance is maintained constant across module to module boundaries and an uninterrupted viewing surface over the entire screen results.

The LED array matrix in each module consists of 64 electrical rows and 64 electrical columns. These are interconnected to hybrid driver circuits mounted to each side of the module (Figure 2-2) by means of deposited metal conductors and embedded bond wires. The row hybrids contain a set of eight octal shift registers and constant current source ICs. The column hybrids comprise two sets of four-sixteen channel current sink ICs. Both source and sink ICs utilize state-of-the-art I^2L technology and both have been custom developed for MMM type LED flat panel displays. Both hybrids are designed for hermetic sealing and will be tested and qualified to MIL-STD-883 either as separate components or as an integral part of the complete LED module. The LED array is protected from dirt, moisture and possible handling damage by a transparent encapsulation. The LED module is a plug-in assembly with miniature multi-pin connectors providing electrical connection to a back-plane interconnection board.

Operation of the LED array involves the sequential addressing on each column of the 64 x 64 matrix. The maximum available ON time for each LED is therefore 1/64 of the total array scan time. During a given column address interval, a serial data bus loads data for the subsequent column into the row hybrid shift registers, and under control of appropriate timing pulses, the data is parallel loaded into a 64-bit wide latch which controls the constant current outputs directly. On completion of the given column time, the outputs are enabled and all LEDs in the subsequent column are energized for the time determined by the width of the enable pulse. In this fashion all columns in the array are scanned sequentially, all modules are scanned in synchronism. The dual octal driver arrangement and LED pulse width control provides for three shades of grey, including off, and a ready means for manual or automatic brightness control.

Control of array luminance over the full dynamic range is virtually stepless.

A multi-layer contrast enhancement optical filter (complete with embedded transparent conductive coating for EMI suppression) is used to minimize reflections of ambient light from the viewing surface.

The LED module contains a solid core which provides for efficient thermal transfer from the base of the LED array and hybrids to the cold plate heat exchanger. Under worst case display loads, LED and IC junction temperature rises, relative to the cold plate, do not exceed 10°C.

With the display surface configuration as described above, the ADM displays have been shown to have excellent legibility for incident ambient light levels varying from 10^{-4} to 10^{+4} ft C.

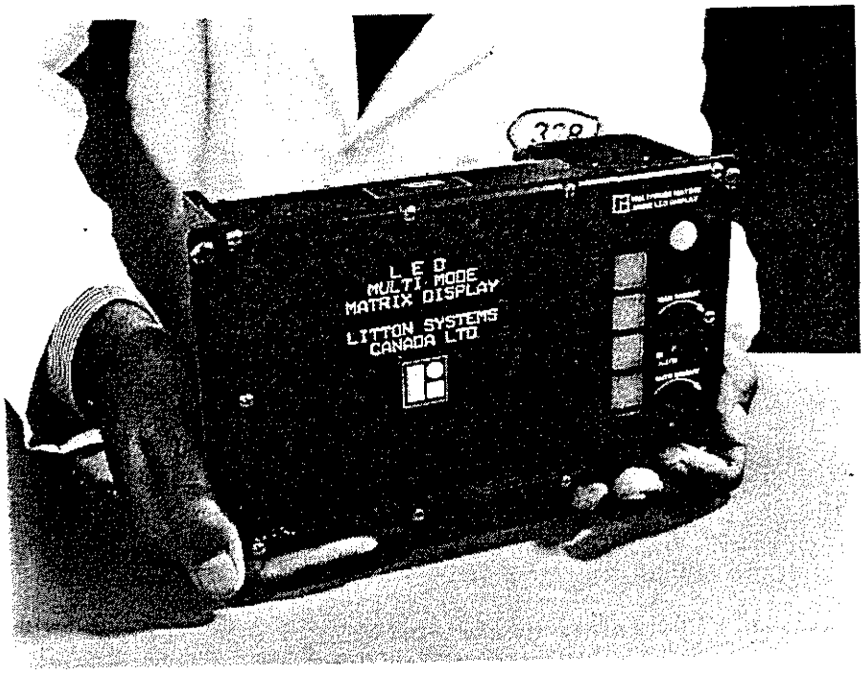

Figure 2-1 ADMI Display Head

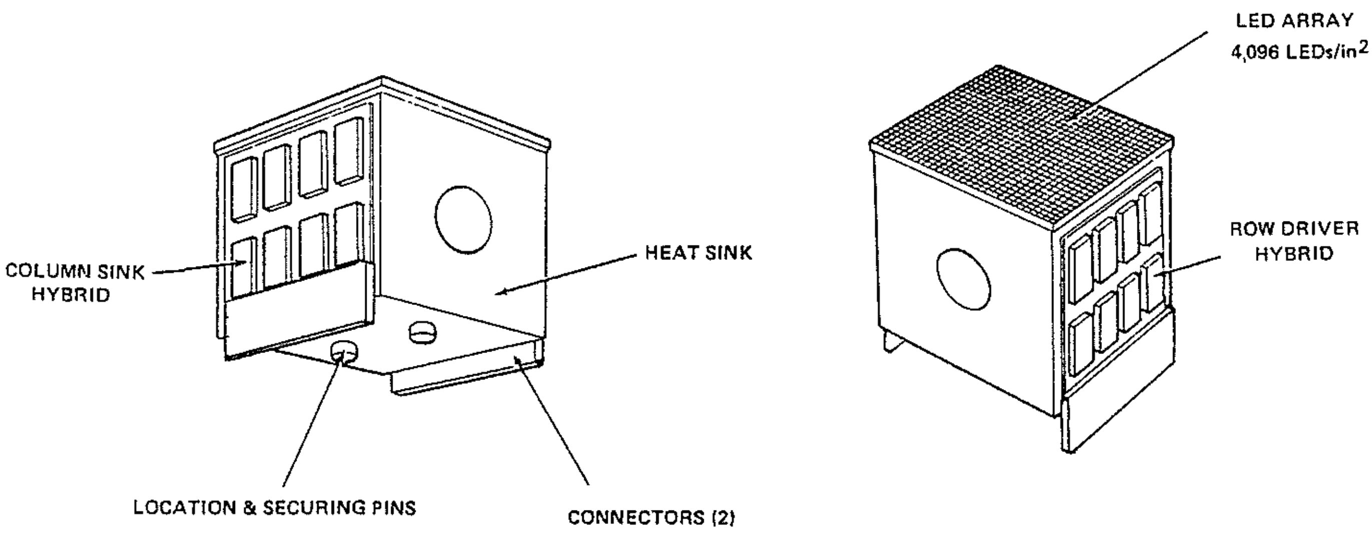

Figure 2-2 LED Module

3.0 ADM I - NON FLYABLE PROTOTYPE

Following the successful manufacture and testing of the Concept Demonstrator, construction of the first full performance prototype MMM system was initiated. This is known as Advance Development Model I (ADM I).

ADM I has been designed as a non-flyable, but fully functional multi-mode display system. It will accept as inputs typical avionic data such as pitch angle, roll angle, heading, altitude, etc., and typical aircraft system data such as engine status. It will provide as an output, one of several display formats according to the operational mode selected by the operator or pilot. Thus the ADM I type of MMM display system may be used for a wide variety of functions on board the aircraft, and may be used in a mission dependent fashion, i.e., each display surface on the aircraft will be used as part of a display suite (assuming more than one multifunction display is installed) to provide the pilot with the optimum set of information that he requires for that phase of the mission.

Currently all the hardware for ADM I has been manufactured and tested, and software has been written. The ADM I is scheduled for delivery to Wright-Patterson Air Force Base (Ohio) for the start of evaluation experiments at the end of November 1981.

Following delivery of the ADM I to the AFFDL, the USAF Crew Systems Development Branch at Wright-Patterson Air Force Base, will subject it to an extended and intensive period of testing. The bulk of these tests will be conducted with the ADM I located in a simulator cockpit. The simulator (and hence the displays) will be driven by two computers which will contain the aerodynamic equations of motion for a USAF attack aircraft (the A7).

The primary features of the ADM I are:

- 10 cm x 12.5 cm display area constructed using 2.5 cm square 'production' LED display modules.
- 7 different formats.
- DMA computer interface.
- 500 Hz refresh rate.
- 250 Hz display data update rate.

The ADM I was designed to provide a high degree of flexibility in terms of performance and displayable formats, and to meet the projected requirements of new experimental display formats currently under investigation at Wright-Patterson Air Force Base.

3.1 Architectural Overview

A block diagram of the ADM I system is shown in Figure 3-1.

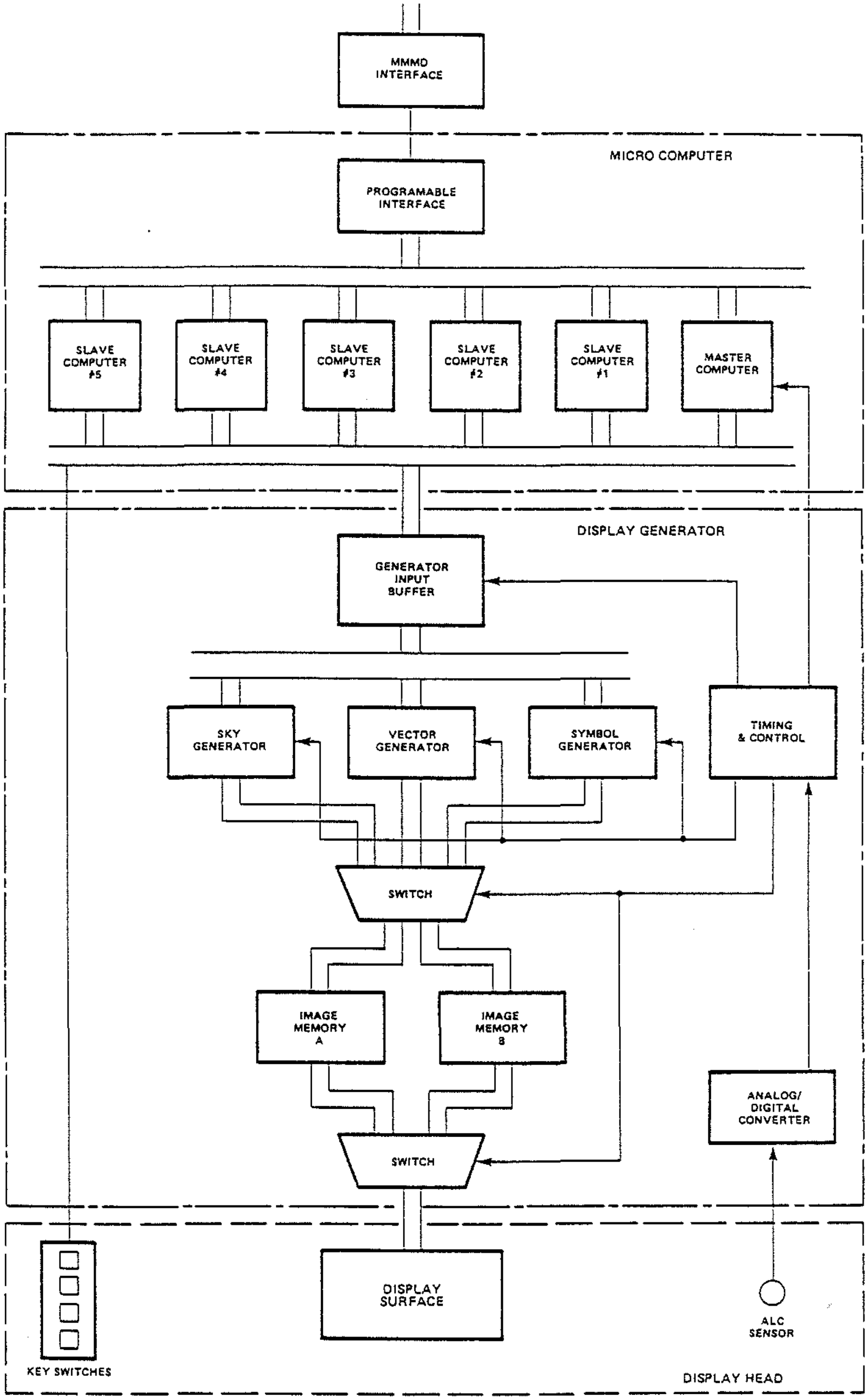

Figure 3-1 ADM I Block Diagram

Avionic data, aircraft system status, and display mode commands are all passed to the ADM I from the Simulator Computer via a Digital Equipment Corporation (DEC) DR11-B computer interface. From here the data passes into the microcomputer.

The microcomputer has been designed to provide an unusual degree of power and flexibility for a display system. It is comprised of six sub-computers, each containing its own processor (Intel 8086), and its own memory. One of these, the master computer, is responsible for communications with the Simulator Computer. When a display mode change command is received from the Simulator Computer, the master computer responds by loading each of the slaves with the appropriate block of code for the required function. All format code is held in EPROM in the master computer. The slave computers contain no EPROM and only sufficient RAM to hold the instructions required for one format and its associated data files.

After avionic data has been received by the master, and some pre-processing carried out, it is sent to each of the slaves. It should be noted that each slave is operating on a slightly different set of avionic data from its neighbour, i.e. if slave number 1 is using aircraft data that was correct at time T, then slave number 2 will be using aircraft data correct at $T + \Delta$, where Δ may vary from 20 milliseconds down to 4 milliseconds. The output of each slave consists of a set of display generator commands in the form of sky boundaries (if applicable), line or vector end-point co-ordinates, and symbol or alphanumeric type and coordinates. The outputs of each of the slaves are transmitted to the display generator as dictated by the master.

There were two main reasons for selecting a multi-processor parallel architecture such as this:

- It allows a very powerful data processor to be constructed in an efficient way.

- It allows the computer power to be easily tailored (by the removal or addition of further slaves) to the particular application.

The high power is achieved without the loss of flexibility that would be incurred by a largely hard-wired design.

It is believed by the researchers at Wright-Patterson Air Force Base that this capacity for a very high output data rate (achieved if necessary by the interpolation of input data), coupled with the high-speed characteristics of LEDs, will result in enhanced display readability in fixed-wing and helicopter environments where factors such as high acceleration and vibration are prevalent, than was previously possible using CRTs.

At an appropriate time, the slave computer data is transferred to the input buffer of the display generator by the master computer. While this is taking place, the display generator accesses another part of the buffer to obtain commands for the sky, vector, and symbol generators. These sub-generators use the input commands to produce specified LED on/off data which will combine to form an image. The vector generator is a digital differential analyzer (DDA), and the symbol generator is essentially a look-up table containing the LED on/off patterns for a predefined set of alphanumeric characters and symbols.

The image data from the generators is fed on alternate cycles into image memory A and image memory B. That is, while the generators are loading memory A, the display surface is being refreshed (at 500 Hz) from memory B. When the loading is complete, the image memory input and output switches are reset, and the display surface is refreshed from memory A, while the generators load memory B. The switching rate is governed by the required format update rate (up to 250 Hz).

The simulator computer interface, microcomputer, display generator, and the associated power supplies are contained in one ATR box.

The ADM I display head is shown in Figure 3-2, together with the electronics unit. In addition to 20 fully abuttable modules, the display head contains four programmable function pushbutton switches, a sensor for automatic luminance control (ALC), a knob for manual luminance control, and a knob for setting the desired level of image legibility. An analog signal from the ALC sensor and controls is converted to a digital format in the display generator. This signal is 'shaped' to correspond to the combined characteristics of the human eye brightness perception, and then used to pulse-width modulate the supply current to the LEDs to obtain the desired luminance.

3.2 Display Formats

The following display formats will be available on ADM I for simulator experiments at Wright-Patterson Air Force Base. Although they reflect the fact that an A7 fixed-wing aircraft is the simulator model, no special significance should be attached to this, as similar formats could easily be developed for other aircraft.

- Engine Status Indicator (Conventional) (Figure 3-3). The format provides a bar-graph representation of engine parameters. It is a significant advance over mechanical gauges but does not present data in an optimum fashion.

- Engine Status Indicator (Advanced) (Figure 3-4). This is a Multi Mode Matrix representation of a type of format (developed at Wright-Patterson Air Force Base) which has found considerable pilot acceptance during experiments, and results in improved readability over the conventional flat panel format. It contains more information than the conventional format, and is one of a series of formats that are being developed by the Crew Systems Development Branch, which will exploit flat panel technology in the next generation of aircraft.

- Electronic Attitude Director Indicator (Figure 3-5). This is a MMM representation of a conventional ADI format.

- Electronic Horizontal Situation Indicator (Figure 3-6). This is a relatively old type of display and is not expected to have an extended life on modern aircraft. It has been implemented for comparison purposes, and because of pilot familiarity.

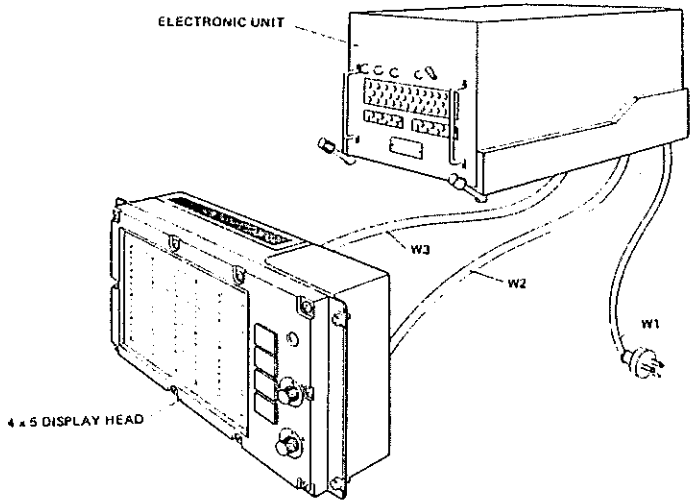

Figure 3-2 ADM I Display Head and Electronics Unit

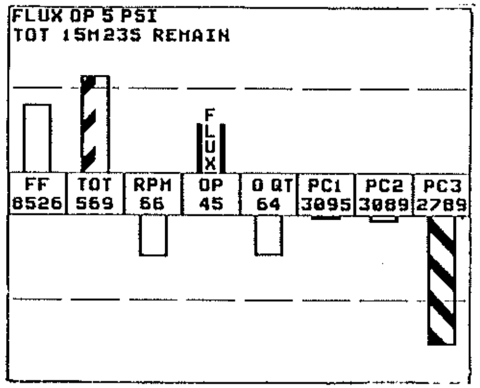

Figure 3-4 Engine Status Indicator (Advanced)

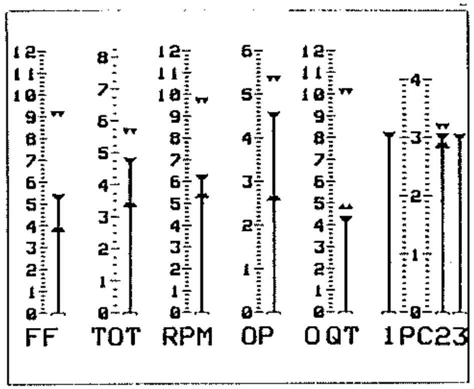

Figure 3-3 Engine Status Indicator (Conventional)

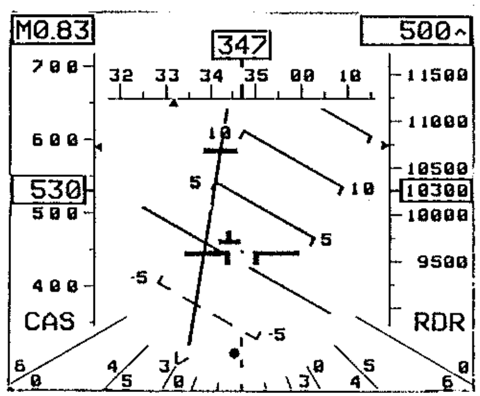

Figure 3-5 Electronic Attitude Director Indicator

- Navigation Indicator (Figure 3-7).

- Precision Approach Indicator (Figures 3-8, 3-9, and 3-10). This represents an experimental class of formats that are currently being investigated, and have not yet been flown.

Although this represents the complete (at present) list of formats being implemented on ADM I, there are a large number of other formats that have been considered. These include check lists for take-off and landing, stores management, weather data, and an experimental helicopter cockpit control deflection display.

3.3 Human Factors Experiments

The flight simulation experiments at the AFFDL will be conducted in two phases. For Experiment 1 of Phase I, the hypothesis that will be tested is that 'Pilot performance improves with increases in display data rates'. During this experiment, the EADI format shown in Figure 3-5 will be used on ADM I.

The pilot will be required to fly a mission consisting largely of a series of vertical "S" proficiency manoeuvres. These manoeuvres are used in training to improve the pilots cross-check and aircraft control, and hence will be familiar to the experimental subjects. They were selected because they are taxing to fly, and require constant use of the Attitude Director Indicator. The mission is shown and described in Figure 3-11. During each test, a series of measurements will be taken of parameters such as bank angle, airspeed, vertical velocity, and stick position. A total of about twenty pilots will be used for the tests. In order to test the hypothesis, the mission will be repeatedly flown (allowance will be made for learning distortion) using different avionic update rates, (i.e., the rate at which avionic data is fed to the display computer), and perhaps more importantly, using different display update rates, (i.e., the rate at which new data is incorporated in a format being viewed). Note that the display update rate is not to be confused with the refresh rate. Display update rates will be used that are in excess of the inherent capabilities of CRTs and other technologies.

Various types of error data will be generated for the analysis. This will be performed using a computer-aided multivariate analysis of variance (MANOVA), and finite intersection tests (FIT).

Experiment 2 of Phase I will utilize some of the remaining formats, while horizontal proficiency manoeuvers are flown. A slightly different cockpit configuration will be used.

In Phase 2 a more radical line of investigation will be pursued. Use will be made of the Phase I results to help design new formats that best exploit the unique visual and physical properties of Multi Mode Matrix LED technology.

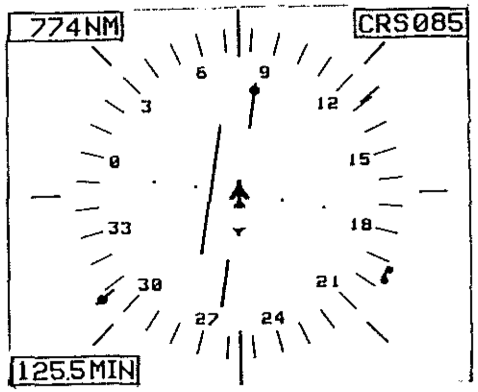

Figure 3-6 Horizontal Situation Indicator

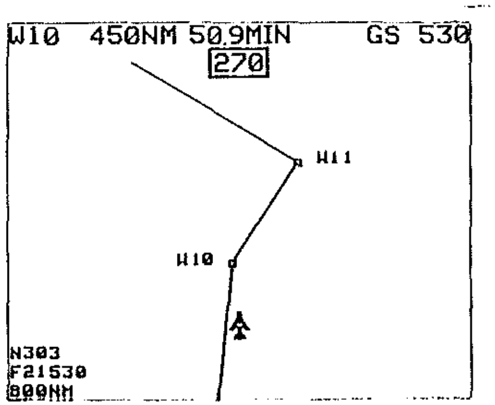

Figure 3-7 Navigation Indicator

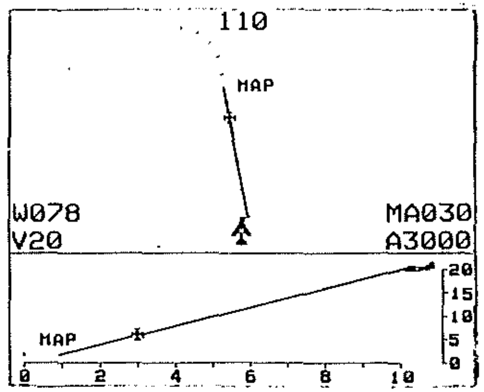

Figure 3-8 Precision Approach Indicator (Stage I)

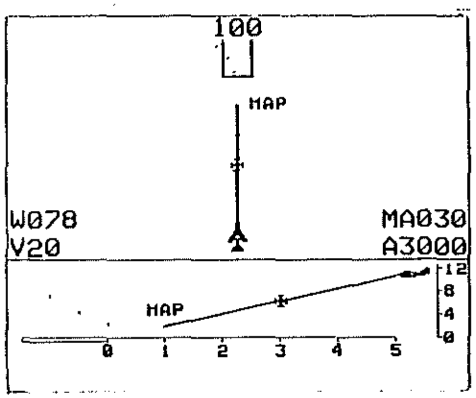

Figure 3-9 Precision Approach Indicator (Stage 2)

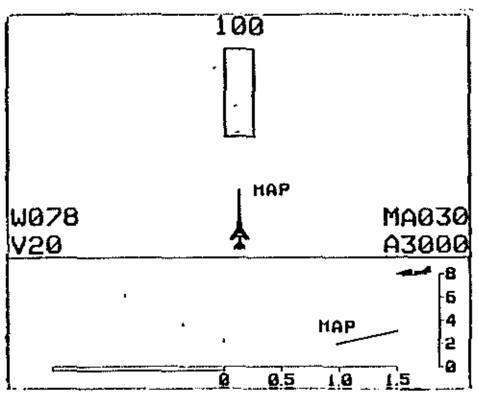

Figure 3-10 Precision Approach Indicator (Stage 3)

1. Maintain 15,000 ft., 300 KIAS and 000°.
2. Turn left to 315°.
3. Change airspeed to 350 KIAS.
4. Turn right to 135°.
5. Change airspeed to 300 KIAS.
6. Turn right to 180° and climb 500 ft.
7. Descend 500 ft.
8. Turn left to 090° and descend 1000 ft.
9. Turn right to 315°.
10. Turn right to 000°.
11. Bomb Drop.
12. Immelmann.

NOTE: Maintain 30° angle of bank when turning and 1000 ft. per minute vertical velocity when changing altitude.

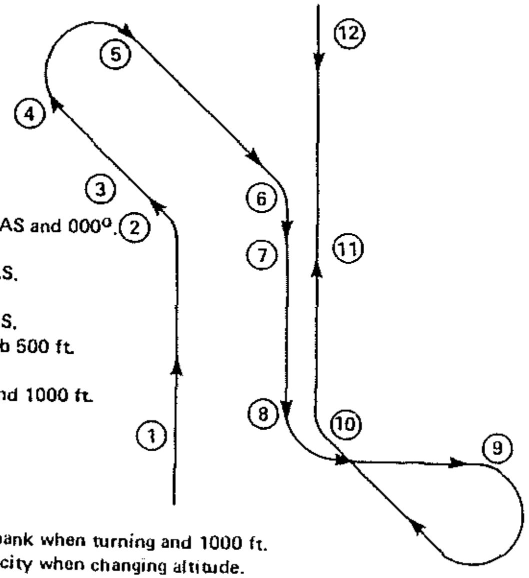

Figure 3-11 Experiment I Manoeuvres

4.0 FURTHER PROTOTYPE SYSTEMS

Two flyable (i.e. meeting airworthiness requirements) prototype systems are also being constructed. These systems have 7.5 cm by 7.5 cm and 12.5 cm by 12.5 cm display surfaces, and are known as Advance Development Models II and III respectively.

The four line replaceable units (LRUs) that comprise ADM III are shown in Figure 4-1. ADM II is identical except for the display head, which is sized for the smaller display surface. The functional design is essentially the same as that used for ADM I, but the hardware has been repackaged to allow potentially easier installation on aircraft such as single seat fighters or helicopters where space will be at a premium.

The avionic interface and the microcomputer are contained in a half ATR box, while the display generator electronics are contained in a second half ATR box. A connecting cable runs between the two boxes. Also connected by cable to the computer box is the display control unit (DCU). The DCU contains the luminance controls that were situated on the display head for ADM I, together with functional mode change switches. This allows a 'cleaner' display head. The DCU may or may not be used when the system is flown, depending on whether the particular aircraft cockpit configuration can use (or requires) its facilities.

The two half ATR boxes are expected to be located in an avionic equipment bay or equivalent. Provision is being made for a MIL-STD-1553B interface in the computer box, although it will be possible to easily replace the avionic interface cards if some other bus system or data system is used on the aircraft. The electrical (cable length) distance between the electronic boxes and the cockpit LRUs, (the DCU and the display head), is not critical. Lengths up to three metres can be accommodated easily, and lengths well in excess of this can be accommodated by the use of a modularized, remote display head power supply. The power supply can be attached directly onto the rear of the display head (resulting in an increased depth of between 3 cm to 7 cm depending on technique) or located at some point in the vicinity of the display head.

It is emphasized that these systems are prototypes and have been designed with flexibility both in terms of aircraft installation and interfacing and performance capabilities. Thus, even if full vector graphic and display system capabilities were required by a customer, the eventual packaging could show significant reductions in the volume of electronics for a production unit.

The hardware design for ADM II and III is virtually complete in all areas except the avionic interface. Although it is anticipated that a MIL-STD-1553B data bus will be used and design work is being conducted accordingly, the interface details will not be finalized until a flight test aircraft is assigned, and indeed could be radically altered if necessary.

ADM II and III are expected to be ready for final configuration and flight test in the first quarter of 1982.

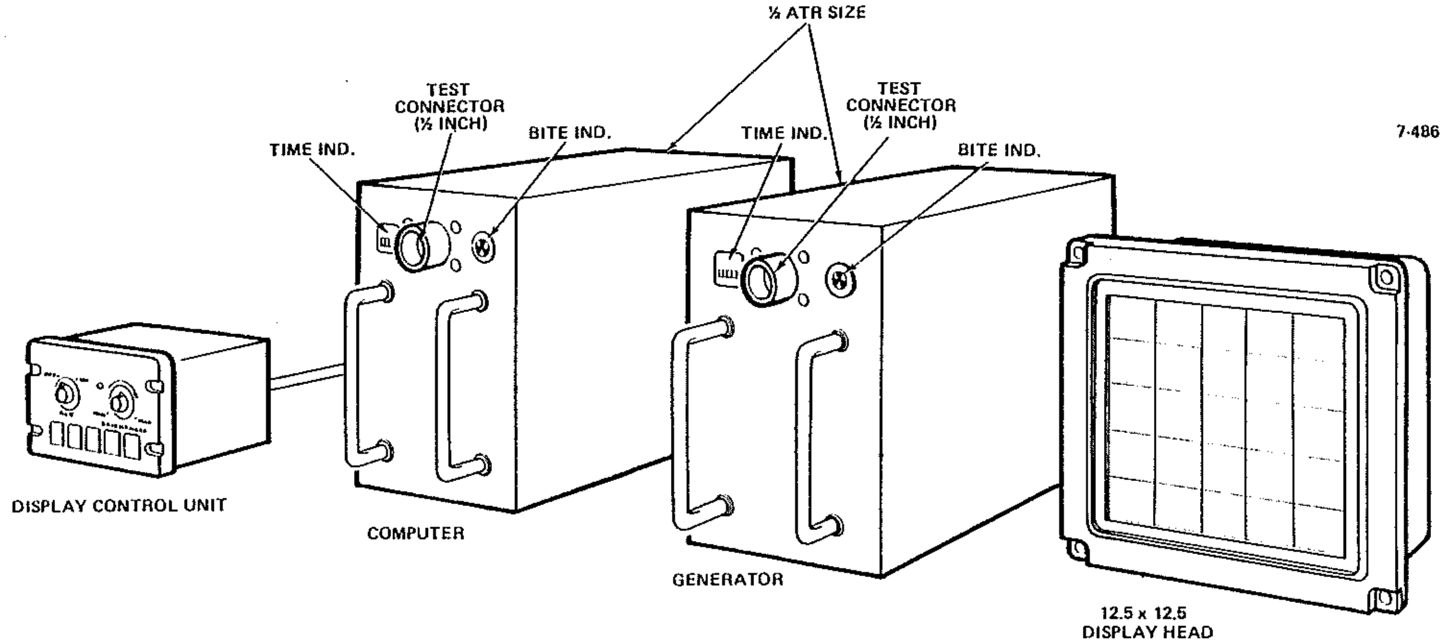

Figure 4-1 ADM III Display System

Litton Systems Canada Limited is especially interested in helicopter applications of MMM technology. The Canadian Government National Research Council (NRC) uses a Bell Model 205 for its programs on avionic research, and has expressed a willingness to consider flight testing one of the Advance Development Models.

5.0 ADM IV - DATA ENTRY DISPLAY

The ADM IV 3 in. by 1 in. display is intended for experimental evaluation in an advanced cockpit simulator. As in all of the ADM systems, each LED module contains 4096 individually addressable green LEDs on 0.016 inch (406 micron) centres.

While the display will have the basic capabilities for fully flexible vector-graphic and alphanumeric presentations, it will be evaluated primarily as a versatile multi-function type of data entry display. For this purpose, the unit will contain sufficient PROM for a resident store of 128 characters and be capable of presenting a full screen of 7 x 9 and/or 8 x 11 characters.

The internal operations of the ADM IV are controlled by a single INTEL 8086 microprocessor. Signal inputs, in the form of character codes, are received from the host (simulator) computer over a 9600 baud RS232 interface, stored in buffer RAM and accessed by the microprocessor in response to timing and control logic. The microprocessor then addresses a character generator which generates the dot matrix pattern for each character.

Brightness of the displayed characters is achieved by varying the LED duty factor under the control of an input analog voltage.

Basic characteristics of ADM IV include the following:

<u>Format</u> - up to four evenly spaced lines of eighteen 8 x 11 characters per line, or up to five evenly spaced lines of twenty-one 7 x 9 characters per line.

<u>Character Size</u> - (8 x 11) - 3.1 mm W by 4.3 mm H

- (7 x 9) - 2.7 mm W by 3.5 mm H

<u>Contrast Ratio</u> - greater than 2:1 in 10,000 fC at maximum drive.

<u>NOTE</u>: Contrast ratio is defined here as:

$$C_R = \frac{L_S - L_D}{L_D}$$

where: L_S = luminance of lit pixel including reflected ambient.

L_D = reflected ambient from unlit pixel.

Input Luminance Control	-	0 - 5 Volts, 400 Hz, dimmest at 0 Volts
Refresh Rate	-	500 Hz
Update Rate	-	10 Hz
Transmission	-	ASCII

6.0 FUTURE DISPLAY DEVELOPMENTS

The feasibility of manufacturing other display configurations or other display orientated avionic equipment that would exploit the developed MMM technology has been pursued in several directions.

One of these is the head up display (HUD) mounted display. Because of its physical construction, the HUD used in modern aircraft presents a flat surface in the cockpit just below the optical combiner. The surface is located in a prime display location, but because little depth is available (due to the presence of HUD optics) it is usually only used for locating switches or special purpose lamps. LSL has demonstrated the feasibility of attaching a shallow MMM display on the front of the HUD. The display would be similar in architecture to that of ADM II or III.

A more radical investigation into the applications of MMM technology took place when the feasibility of building an MMM based multi function keyboard (MFK) was examined in 1980. The MFK concept, which is being investigated by AFFDL involves the control of several pre-designated avionic systems, and the computer controlled replacement of keyboard switch legends and switch functions.

The MFK design considered by LSL consisted of fifteen pushbutton switches, each of which could be used to display any desired legend made up from alphanumeric characters or special purpose symbols. A small scratch pad display was also included on the unit to show keyed in digits and to provide system responses or messages.

At the highest level of the control hierarchy each switch might represent a complete avionic system (Communications, Radar, etc.) and selecting a given switch would cause the keyboard to reconfigure itself with commands suitable to that system. At the lowest level of the hierarchy, each switch might represent a discrete digit (to allow a new communications frequency to be entered, for example).

It is expected that this means of avionic system control will result in significant improvements in cockpit design in all classes of aircraft in the future. MMM technology provides the combination of flexibility and robustness that it requires.

The previously discussed systems have all reached the design stage in that further display surface development activity is not required prior to production. Display surface development is currently being considered that would lead to video or TV type displays, and multi colour displays. Preliminary studies have provided positive results in both of these areas. A high grade video display would require an increase in LED density by about a factor of 4 in terms of LEDs/in.^{2}, and an ability to provide at least 8 visible tones. LED brightness may be varied by changing the drive current, or the duty factor, or by a combination of both. The circuitry changes that this would necessitate could be incorporated on the module by using new hybrid microelectronic ICs. Likewise, the density increase is not thought to present a serious obstacle, but would require re-engineering the module as it is currently produced. With respect to colour, green emitting (565 nm) LEDs have been selected for general use to date. This is based on consideration of compatibility with the human eye, and psychological colour associations (e.g., red for danger, etc.). LEDs can be supplied in the primary colours of red, green and blue although the efficiency of blue LEDs is too low at present to use. A multi colour MMM display could be developed using red and green LEDs combined with a single pixel, but this also would require re-engineering of the module and has not yet been fully investigated at these densities.

7.0 CONCLUDING COMMENTS

It is clear that LED flat panel technology has approached a level of maturity consistent with that required for helicopter and military environments. In parallel with the evolution of flight worthy hardware, a thorough evaluation of the human factor aspects of dynamic vector graphic displays will shortly be performed by the USAF Flight Dynamics Laboratory at Wright Patterson Air Force Base.

Display imagery portrayed on a LED array has characteristics which differ from those of a CRT particularly with regard to the clarity and sharpness of image detail. While this provides a distinct improvement in image legibility as compared to a CRT, it tends to highlight the resolution limits of the 24.6 dot per cm (62.5 dot per inch) matrix in some display formats. For example, sloping lines exhibit a 'staircase effect' the magnitude of which depends on the slope angle. Also, for rotating vectors, the apparent perturbation of line segments depends on rotational speeds, i.e., aircraft roll rates and display update rates and requires close attention to display format and software design to preserve smooth image motion. As mentioned in Reference 3, the reaction of some thirty-five pilots to the MMM Concept Demonstrator display, when operated in the electronic attitude director (EADI) mode during a preliminary testing program, was favourable, and tended to confirm the correctness of the basic system design objectives and performance criteria. The current AFFDL simulation program is expected to again confirm this result but over a much wider range of operational conditions.

In conclusion, the present status of LED flat panel technology, as represented at least by the MMM project and relative to helicopter and military environments, may be summarized as follows:

- Solid-state flat panel displays suitable for use in helicopter cockpits are presently achieveable using LED technology.
- The full capabilities of 24.6 lines/cm (62.5 line/in.) LED displays relative to vector graphic displays have not yet been fully assessed but initial results are promising.

- The minimum panel thickness for LED displays depends on the specific features of the installation, but behind-the-panel mounting depths of less than two inches are feasible. This is expected to be especially beneficial in those helicopter applications where it is advantageous to locate the display as close as possible to the windshield in order to reduce possible disorientation when both the outside world and the display data must be assimilated in succession.

- The present potential in LED flat panel technology is substantial with the development of 50 line/cm (128 line/in.) video systems and lower resolution multi-colour systems are expected within the next two years.

Finally, it seems reasonable to conclude that for vector graphic display applications in the helicopter cockpit, state-of-the-art LED flat panel technology offers new opportunities to the crew station designer.

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