THE APPLICATION OF MICROPROCESSOR TECHNOLOGY TO IN-FLIGHT COMPUTATIONS

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INTRODUCTION

During the past decade, electronic microcomponent technology has developed to the point where microprocessors are appearing in an expanding number of diverse applications. Improved manufacturing techniques have allowed the computing power of the microprocessor to increase at the same time its physical size has decreased. The mass production of these tiny high-powered components has made them readily available for nominal costs to industry, research, government, and private individuals.

The application of this new technology proposed by the authors is a microprocessor-based system to essentially replace current panel instrumentation in sailplanes. A microprocessor-based system is particularly attractive for in-flight computations because of its accuracy and dependability, but more importantly because of its potential for flexibility of output. Given the two basic input values of dynamic and static pressures, the system could perform the functions of a conventional panel by providing the pilot with airspeed, altitude, and variometer readings, but could also be programmed to provide him with additional data at his request. Since all microprocessor-based systems contain an internal clock, time history data and moving averages could be computed. The microprocessor could easily handle computations involving integrations or requiring the manipulation of many data points or solutions of complex equations.

This paper will present a modular design of a general purpose microprocessor-based computer to perform in-flight computations for cross-country soaring pilots. The basic requirements for the system will be discussed. Several specialized applications of the computer will be presented, including real-time pilot feedback and flight-test data acquisition and reduction.

CURRENT INSTRUMENTATION

A brief examination of the instrumentation in current, competition sailplanes will reveal part of the motivation behind the microprocessor-based panel. An excellent overview of present-day instrumentation is contained in reference 1.

Today's airspeed indicators and altimeters, although simple and reliable, suffer from position errors caused by incorrect static-pressure sources. In

the case of the airspeed indicator, the relocation of static ports in the fuselage between the wing and the tail has eliminated the major portion of this error. The remaining correction can still be significant, however, especially when performing flight tests. The static-pressure source for the altimeter is usually cockpit pressure, for reasons which will be discussed later. In addition to this position error, altimeters have added problems caused by high relative friction forces within the instrument. This friction results in the sticking problems known to all sailplane pilots.

Present-day variometers are of two types — those which measure pressure differences and those which measure mass-flows. The pressure variometers have no altitude errors, whereas the mass-flow variometers exhibit a rather large altitude error, approximately 10%/3000 ft.

Of the four available pressure variometers, two are mechanical and two are electrical. The first, and presently most common, mechanical type is the classic vane variometer such as the PZL or Winter. This type is quite reliable, but has several disadvantages which include relatively slow response due to friction, close-tolerance construction, delicate mechanisms, and susceptibility to dirt. The second mechanical type, the taut-band variometer produced by Schuemann or Bohli, has a fast response. It also has some inherent problems, however, associated with tuning the required capillary and producing the delicate metal-band assembly.

The two electric types have the common virtues of fast response and audio capability. They also share the disadvantages of possible unreliability because of the required power source and wiring, and a response which is "too fast" and thus requires damping. The most common of this type, the capillary-leak variometer made by Ball, has further difficulties arising from the capillary which must be tuned and the close tolerances on the linear variable differential transformer (LVDT). The second type is the altitude derivative variometer (ref. 2). This variometer is expensive to produce because it requires a pressure transducer.

Mass-flow variometers, such as those made by Cambridge or Moore, incorporate thermistors which require some degree of matching.

All of the variometers mentioned above require total-energy and/or netto compensation. Total-energy compensation is usually provided by either an Althaus-type venturi or a diaphragm. The venturi, as well as similar devices such as Braunschwieg, Nicks, and Irving tubes, provides accurate compensation independent of altitude. They are, however, relatively sensitive to horizontal gusts, require careful positioning on the sailplane, and add drag. They also do not work well, if at all, in rain. A diaphragm compensator, such as the PZL, Winter, or Burton, does not increase the drag of the sailplane. It does, on the other hand, compensate exactly at only one altitude. Although less sensitive to gusts than a venturi, it is difficult, if not impossible, to correctly adjust. Recently, electronic compensation has been introduced, which incorporates thermistors like those in the electric mass-flow variometer. These thermistors require some matching.

In addition to total-energy compensation, netto compensation is also desirable. This compensation requires a capillary which can be tuned to approximate, but not necessarily exactly "fit," the given sailplane's polar. With this system, it is difficult to account for weight changes such as the addition of water ballast.

Regardless of type, all current instrumentation suffers from several problems. None of today's instruments are truly temperature-compensated. Because the entire system is pneumatic, the various pressure sources and instruments must be connected by tubing. This tubing adds volume to the system and introduces the possibility of leaks. Refinements to the variometer sub-system require additional restrictors and/or gust filters. While solving some problems, these devices have problems of their own, such as time-constant matching (ref. 3). Also, the interaction between the various instruments can cause difficult problems. These problems arise from the interaction of several diaphragms (airspeed, total-energy, and altimeter) through the variometer on the common static-pressure line. Disconnecting the altimeter from the static-pressure line alleviates part of this problem.

In summary, the instruments currently available are certainly adequate for safety, but are somewhat inadequate for efficient cross-country flight for the following reasons:

(1) The information they provide is not accurate for all altitudes, attitudes, and environments.

(2) To correct some of the errors inherent in the instrumentation, the devices for measurement and display have become inordinately delicate and complicated.

(3) The current equipment offers no facility for flexibility or expansion of the type of information provided.

EARLY ATTEMPTS AT IN-FLIGHT COMPUTERS

During the past few years, several attempts have been made to expand the amount and vary the type of information provided to the pilot by his instruments. In 1972, A. Raouf Ismail, of Cambridge Instruments, suggested that an analog air-data-computer (ADC) could provide the pilot with average rate-of-climb and speed-to-fly information during flight, but cautioned that this approach could be bulky, power consuming, complicated, and expensive (ref. 4). That same year, John Firth, of Ottawa, Canada, reported on his work, begun in 1969, involving the coupling of an electric variometer to a simple analog computer (ref. 5). The system performed normal variometer functions with fully electronic total-energy compensation. In addition, the system computed an average rate-of-climb over variable time periods and displayed the correct speed-to-fly using a nose-up/nose-down pitch indicator. Variable damping and sensitivity, variable time constants, and a dry/wet switch allowed

more variables to be adjusted during the computations, and hence provided the input necessary for a more accurate output.

During an average cross-country flight, the analog system was found to be quite reliable, and its flexibility enhanced the usefulness of the information provided. During the World Championships in Yugoslavia in 1972, however, the instrument was used very little because the soaring conditions did not match those for which the instrument was developed, the battery power on board had to be conserved for the radio and gyros, and the pilot's constant attention was required for navigation.

The analog air-data-computer was a definite improvement over standard instrumentation, but was still greatly limited in its flexibility, and, therefore, in its accuracy. In 1974, William Foley presented results of a study involving the use of mini-calculators in soaring flight (ref. 6). Foley's use of a programmable digital calculator partially solved the problem of inadequate flexibility encountered earlier, but introduced other problems which seemed insurmountable given the current technology.

The calculator was not connected to the instruments; thus, all data necessary for program execution had to be entered manually by the pilot. This visual-manual interface was not only slow, but held potential for error. The calculator itself was an obstacle in the cockpit. In order to enter data, a cumbersome kneeboard was required, and to read the LED output, the calculator had to be carefully shaded from sunlight. Depletion of battery power was a concern, and limited memory within the calculator demanded that the pilot load programs from magnetic cards during flight.

Because of these inconveniences, Foley described his mini-calculator as interesting, but impractical. He recognized that the first requirement of any instrument system must be that it provide better or more timely information than the pilot can obtain using his own resources.

REQUIREMENTS FOR AN IN-FLIGHT COMPUTER

The following requirements can be used to define an in-flight computer with sufficient capability to insure that this important condition of faster and better information is met.

Output Capability

1. The in-flight computer must display its output during flight in a format easily readable by the pilot. For example, if the pilot is accustomed to a needle-and-scale altitude instrument, then the in-flight computer must not force the pilot to read a digital display.

2. The system must provide, as a minimum, all information currently provided by standard panel instrumentation. For example, altimeter, airspeed

indicator, and variometer functions must be performed with all types of compensation, filtering, and signal conditioning.

3. The system must provide audio capability.

4. The system must be capable of digital, alphanumeric, and graphic display via an easily readable, glare-free output device.

5. The system must be compatible with other input/output devices, such as flexible disks or printers, for pre-flight system development or post-flight data reduction.

Computational Capability

1. The in-flight computer must be driven by a system clock of sufficient speed to provide real-time information to the pilot. Real-time, in this context, means that the pilot must detect no hesitancy or flicker in the output displays.

2. The system must be more accurate in its computations than standard current panel instrumentation.

3. The system must provide hardware and software signal conditioning capability.

4. The system must be reliable and must provide a self-test capability to verify its integrity during pre-flight checkout.

5. The system must include adequate memory so that time history data may be gathered and stored for post-flight analysis.

6. The system must be built around a microprocessor of sufficient sophistication so that the flexibility that programming allows is not over-shadowed by the complexity of the actual programming process. For example, the system must support high-level languages and feature an operating system that is human-oriented.

7. The system must accept standard programmable read-only memory (PROM) so that standard software can be transported and incorporated easily.

Input Capability

1. The in-flight computer must contain an interface to a standard alphanumeric terminal to be used for program development.

2. The system must allow the pilot to initialize certain predetermined parameters during pre-flight checkout and also during the flight. For example, the pilot must be able to zero his altitude gage before takeoff if he desires.

3. The system must feature an interrupt system that will allow the
pilot to stop the processing of one program and begin the execution of
another in flight with a minimum of effort.

4. Through the use of default parameters, the system must require a
minimum of data entry during flight.

System Configuration

1. The processing and memory modules of the system must be portable
and easily removed from the sailplane for post-flight analysis or program
development.

2. The entire system must be small and lightweight, and must not be an
obstacle in the cockpit.

3. The system must require a minimum of power, and this power supply
should be separate from that required by the radio.

4. The system must be inexpensive.

A MICROPROCESSOR-BASED IN-FLIGHT COMPUTER

The proposed microprocessor-based in-flight computer system consists
of three main subsystems for pressure sensing, computations, and input/output
of information. A functional block diagram showing the major tasks of each
subsystem is presented in figure 1.

Pressure Sensing Subsystem

The major components of the pressure sensing subsystem are two pressure
transducers -- one to measure dynamic pressure and the other to measure static
pressure. Transducers with adequate accuracy and reliability are very small
and can easily be located at the point of measurement, thus eliminating the
need for tubing and its related problems. The analog signals representing
dynamic and static pressures must be conditioned either by circuitry within
the pressure transducer, or by the hardware or software of the computations
subsystem. A photograph of a typical pressure transducer with adequate
sensitivity for sailplane applications is shown in figure 2.

Using the values of static and dynamic pressures, altitude and airspeed
can easily be computed. Uncompensated and compensated rates-of-climb are
merely functions of these pressures with respect to time. Because the system
contains a memory and has access to stored and real-time information, the
values it computes can be corrected for changing parameters, such as altitude
or location on the polar curve. This flexibility will result in an output

that is far more accurate than that available from current instrumentation.

Computations Subsystem

The computations subsystem contains several important components which enable it to handle all of the processing functions of the system. The components are of two main types -- hardware, the actual circuitry that defines the capabilities of the system; and software, the programs that define how the hardware will be exercised to meet the needs of the application. The "brain" of the system is the microprocessor, the selection of which must be guided by several requirements. The microprocessor must operate at a speed sufficient to provide real-time information to the pilot, yet, at the same time, require a minimum of power. It must possess a rapid interrupt-handling feature to enable the pilot to redirect computations instantaneously. The processor word size should be of sufficient length to allow for adequate accuracy during the computations and the addressing of a sizeable memory block. Finally, the processor should be a standard, easily obtainable part that is well-supported by development and checkout software, such as high-level languages and debug packages.

A microprocessor, such as the one shown with two memory units in figure 3, would satisfy these requirements. A typical 16-bit microprocessor will allow the direct addressing of over 65,000 words of memory and the in-direct addressing of many more words. The instruction set is adequate for this application and contains special instructions that allow the rapid processing of interrupts. Several 16-bit microprocessors already boast large user communities, are readily available, and are relatively inexpensive. At this writing, a typical unit price is under $25.00.

The microprocessor cannot function as a computer without supporting components. The memory requirements of the system will depend on the type and number of programs to be executed. The amount of memory can be expanded at any time up to a point depending upon the addressing scheme of the processor and the space allotted for memory on the processor board. Memory in the system will be of two types -- programmable read-only memory (PROM) containing the library of predefined programs, and random access memory (RAM) which may contain instructions or data. The cost of memory represents a large portion of the cost of the computations subsystem, and the memory will also occupy a large portion of the processor board. The cost of memory is rapidly decreasing, however, even though the capacity of each memory unit is increasing. At this writing, 1000 words of memory, packaged as one unit, cost about $10.00.

The processor board will also contain analog-to-digital hardware and some signal conditioning circuitry, depending upon how much conditioning is performed by the pressure transducers themselves, or in the software of the system.

The board may also contain special purpose hardware to perform repeatedly required functions more quickly than software can perform them.

For example, if the applications program involves the manipulation of values of very large or small magnitudes, then these values must be stored in memory as floating point numbers represented by an exponent and a mantissa. Most microprocessors available today perform computations involving floating point numbers much more slowly than those involving fixed point numbers. For this reason, hardware has been developed to perform these floating point computations very rapidly outside the microprocessor. The computations subsystem may operate more efficiently if specialized hardware to meet specific needs is included.

The system will contain a synchronizing master clock and whatever circuitry is required to drive output gages, display screens, or audio devices, and to allow input from switches or keyboards. The entire system will be driven by battery power, which must be regulated by special circuitry on the board. Figure 4 shows a processor board built for another application which illustrates the arrangement of a 16-bit processor, memory, clock, special purpose floating point hardware, and input/output circuitry on a single board.

All processing will be incorporated into a modular computations subsystem, possibly consisting of several boards that may be mounted near the panel area of the cockpit or elsewhere in the sailplane. Because the communication between each of the three subsystems is electrical, not mechanical, the location of the computations subsystem is arbitrary.

Input/Output Subsystem

System input and output will be of two types -- real-time and pre- or post-flight. The format of real-time output must meet the pilot's first requirement that information be timely and easily understood. Since standard needle-and-scale gages inform the pilot of absolute values, as well as the rate of change in these values, then this type of output display should continue to be used at least for airspeed and rate-of-climb information. Additional output desired by the pilot, such as speed-to-fly or altitude, may be displayed using a digital output device or a screen display. The choice of a proper screen display is important. A standard raster scan device, such as a small television screen, while easy to interface to the system, is heavy, cumbersome, requires a great deal of power, and does not provide adequate contrast in the cockpit environment. A liquid crystal display, however, uses ambient light to increase contrast and, therefore, is well-suited to cockpit applications. The digital display shown in figure 5(a) and the top view shown in figure 5(b) illustrate the small size of the liquid crystal display. These devices are also capable of graphic output, as shown in figure 6. A typical panel configuration, including an LCD display, is shown in figure 7.

Input to the system during flight must be minimal and uncomplicated. Select switches and a small numeric/command keyboard must be located in the cockpit where they may be accessed easily, but will not inhibit flying.

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Pre- and post-flight input and output can be more complicated and time-consuming than real-time, but should be streamlined by a carefully designed human-oriented system. A functional grouping of the input and output devices would spare the pilot the task of selecting one of an array of identical pushbuttons while flying.

The entire computations subsystem is modular and portable so that it can be removed from the cockpit and connected to an alphanumeric terminal for system development. Therefore, the interface required to drive such a terminal must be included in the system.

APPLICATIONS OF THE IN-FLIGHT COMPUTER

Because of the flexibility of the system, there are as many applications of the in-flight computer as there are pilots with special interests. Two examples of possible applications are presented here.

The first example is a final glide analysis. At the time that the pilot begins his final glide, he would enter his estimated distance to destination into the system. Since the sailplane's altitude is a parameter known to the system, a display such as the one shown in figure 8 would be output to the graphic display device in the cockpit. As the pilot progresses on his final glide and recognizes a landmark, he would again enter his estimated distance to destination. The system would then update the display with this new information, and also inform the pilot of a new speed-to-fly based on his actual altitude relative to his projected altitude at this point. An updated display is shown in figure 9.

Some pilots may dispute the value of additional real-time information. The second example is one involving flight-test data acquisition. Before takeoff, the data to be gathered would be defined by the pilot and entered into the system. The data acquisition program would begin execution upon command and cause the storage of this data during the flight. After the pilot has landed, a data reduction program could be executed to display the output to the pilot in a useful format.

REMARKS

The state of electronic technology has changed drastically during recent years. Vast improvements in capability have caused electronic components to be considered for diverse applications, such as the in-flight computer discussed in this paper. In the opening address at the 1978 Conference on Man-Computer Communication in Amsterdam, W. J. Doherty of IBM stated that, "it is not facetious to say that this industry is currently rapidly approaching its infancy." (ref. 7).

The impact of this dynamic technology will continue to be felt in the years to come. At this time, it is possible to construct a microprocessor-based in-flight computer to replace current panel instrumentation and greatly improve the quality and diversity of information available to the pilot. The prototype system, however, will be much more complicated, consume more power, occupy more space, provide less capability, and be more expensive than a system built several years from now to meet the same requirements. Hardware costs and power requirements are falling, even while capability per unit is rising. Figures 10, 11, and 12 show trends in the cost of processors and the cost and density of memory that substantiate this projection.

While the capability/cost trend of the in-flight computer will probably not rise as sharply as that of more marketable items, such as hand-held calculators, the system should be within economic reach of the average soaring pilot within the next few years.

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I/O SUBSYSTEM   COMPUTATIONS SUBSYSTEM

PRESSURE-SENSING
SUBSYSTEM

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+----------------------+        +----------------------+        +----------------------+
| GAGES                |        | PROCESSOR            |        |                      |
| AUDIO                |        | A/D CONVERTERS       |        | PRESSURE TRANSDUCERS |
| ALPHANUMERICS        |<------>| SIGNAL CONDITIONERS  |<-------|                      |
| GRAPHICS             |        | INTERNAL CLOCK       |        |                      |
+----------------------+        +----------------------+        +----------------------+
        ^
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        v
+----------------+
|    PILOT       |
+----------------+
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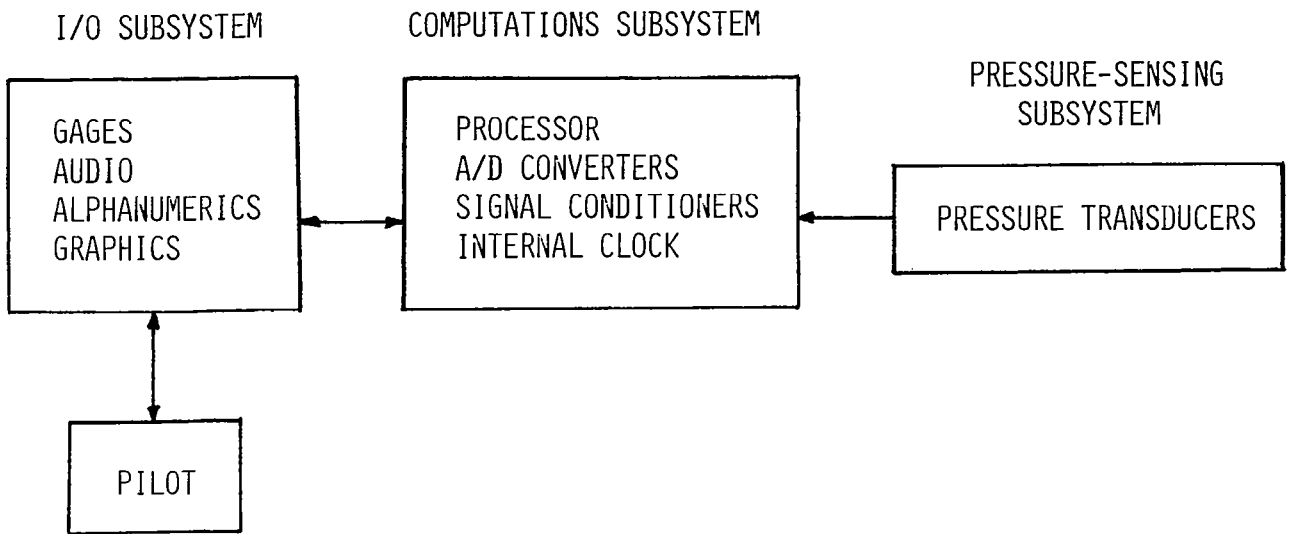
Figure 1.- Functional diagram of an in-flight computer system.
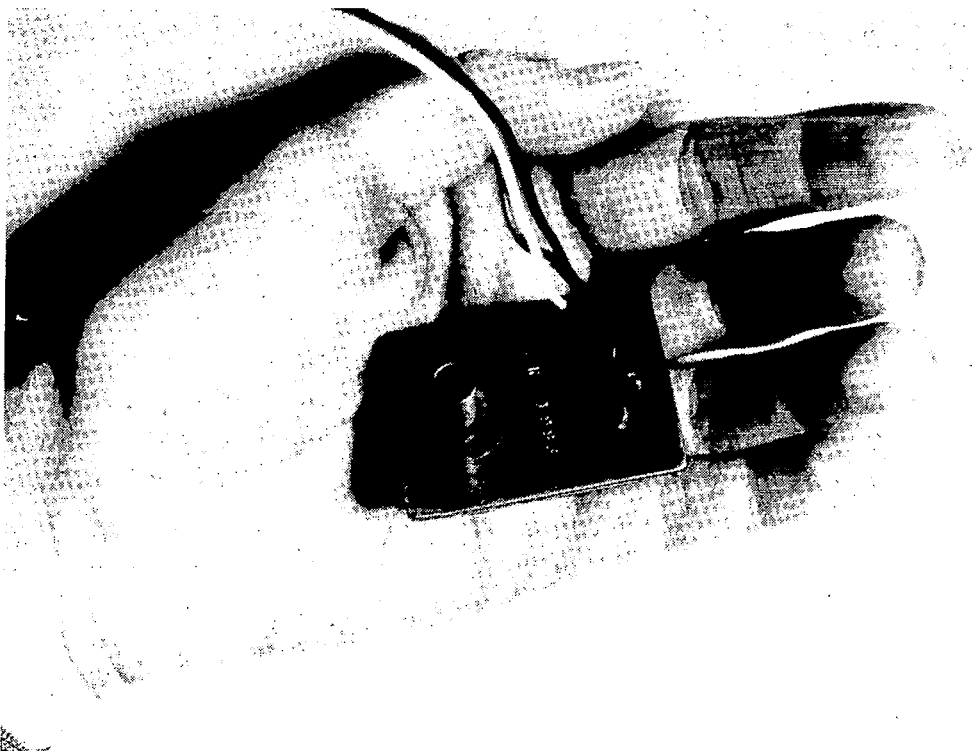
Figure 2.- Typical pressure transducer.
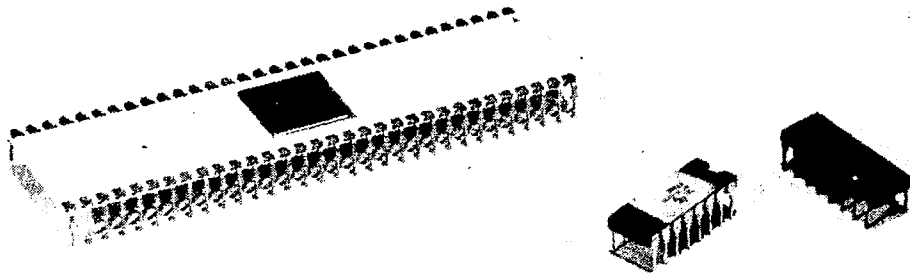
Figure 3.- Typical 16-bit microprocessor (left)
and memory units (right).
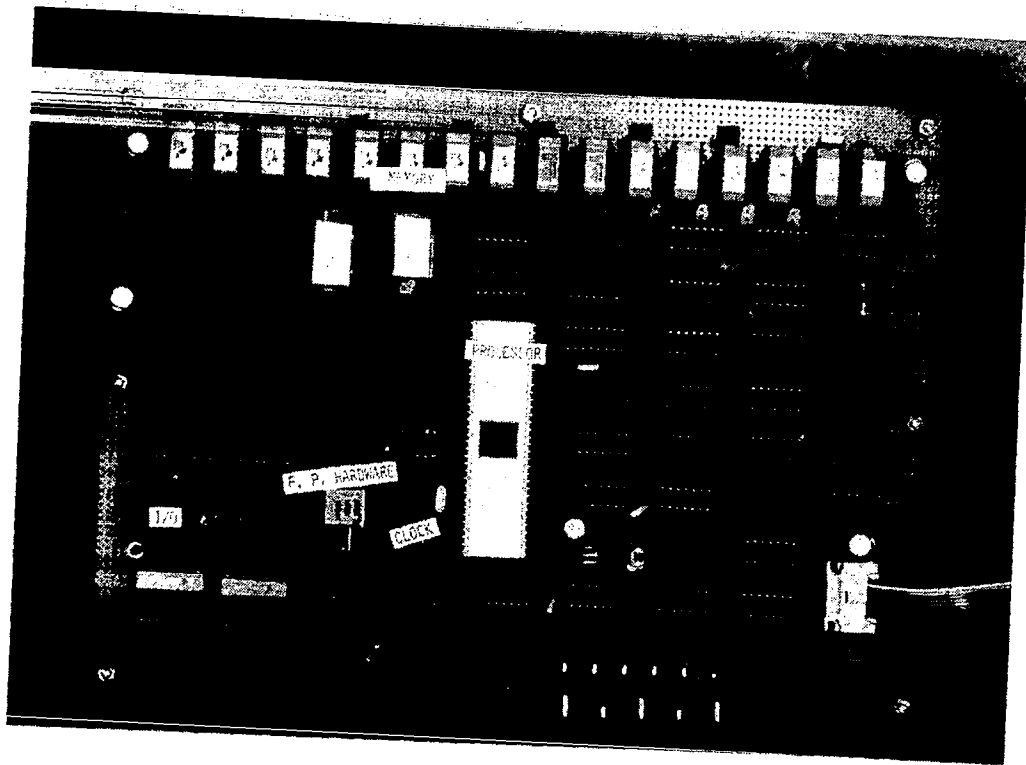
Figure 4.- Typical prototype microcomputer.
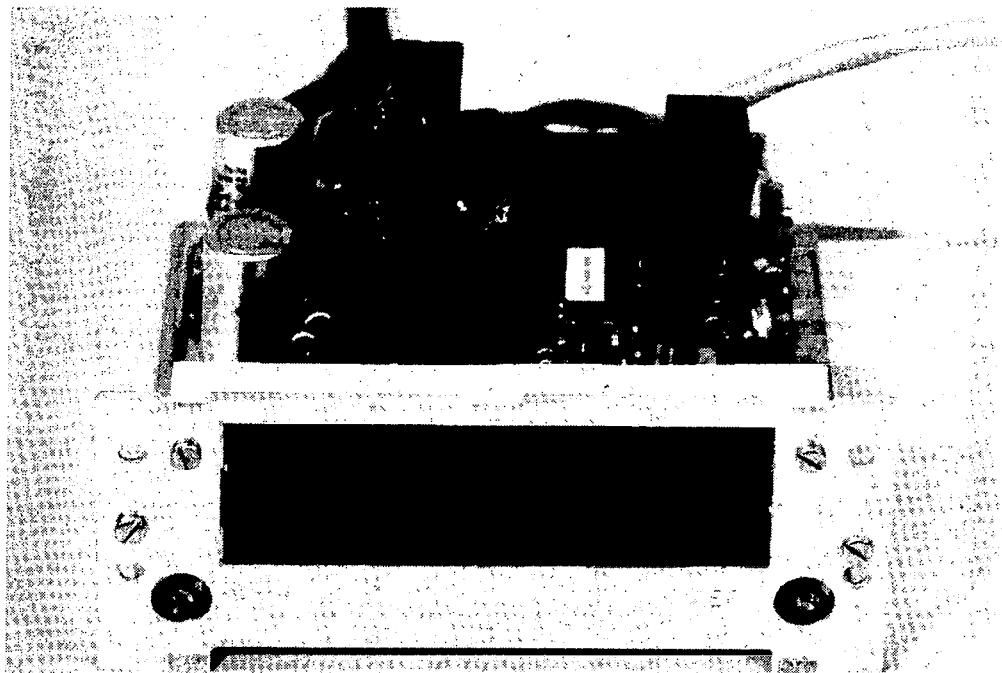
(a) Front.
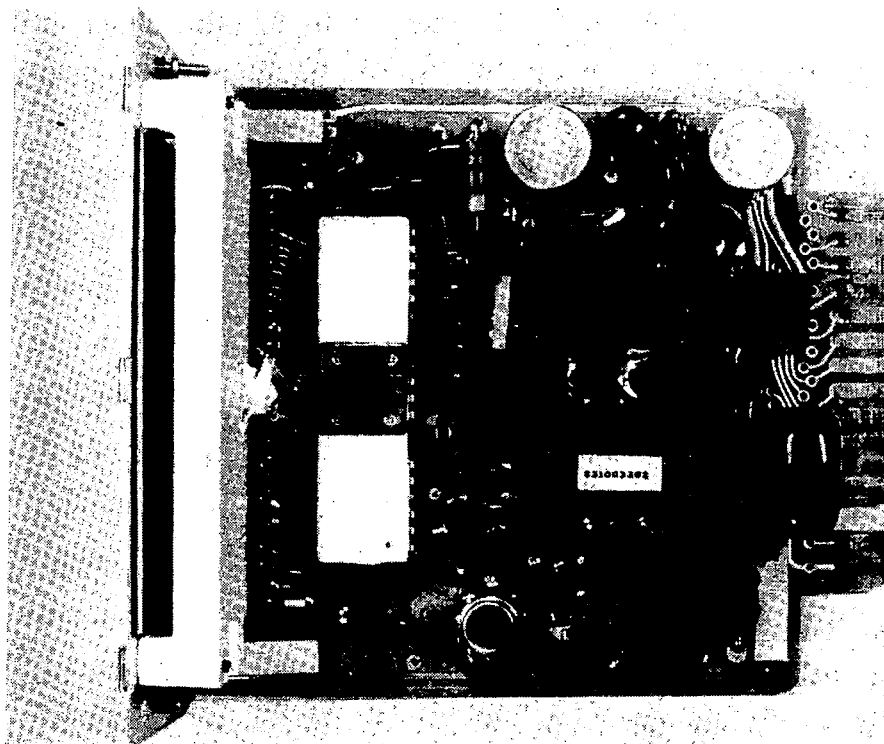
(b) Top.

Figure 5.- Typical digital liquid crystal display.

LIQUID CRYSTAL
MODULES

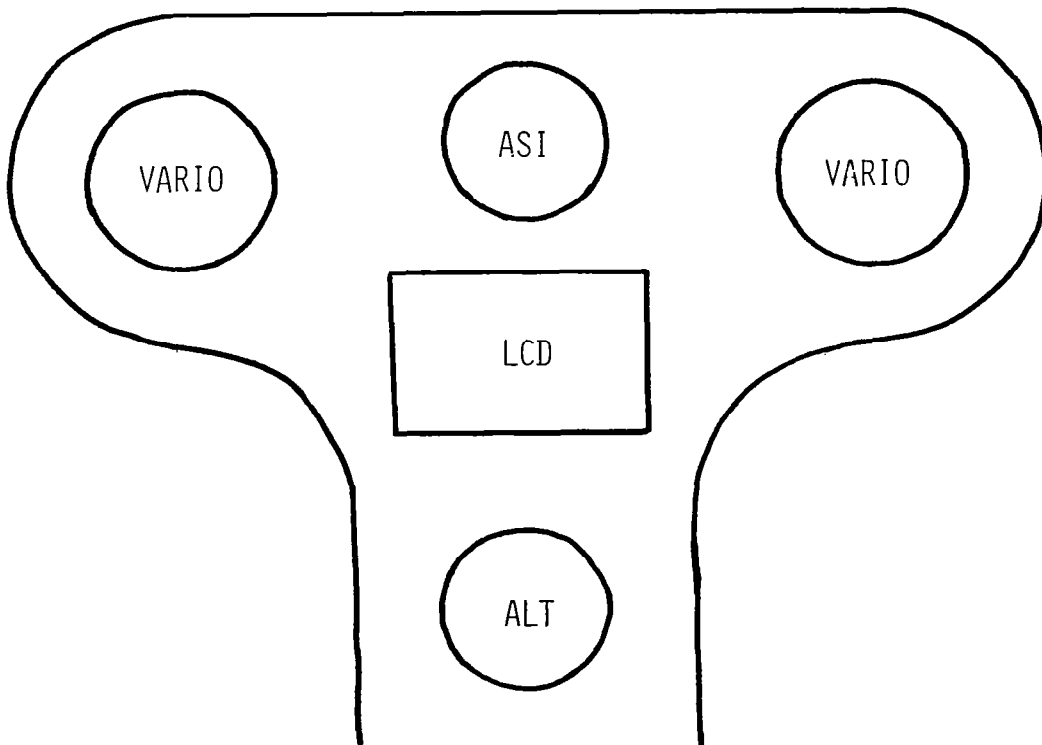Figure 6.- Liquid crystal module capable of graphics output.

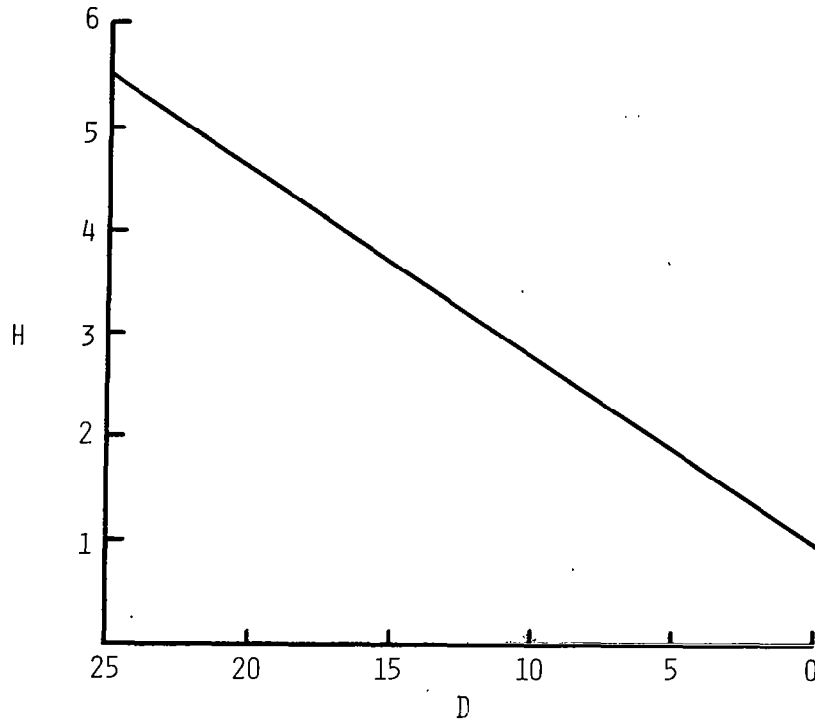Figure 7.- Proposed minimum cockpit panel.

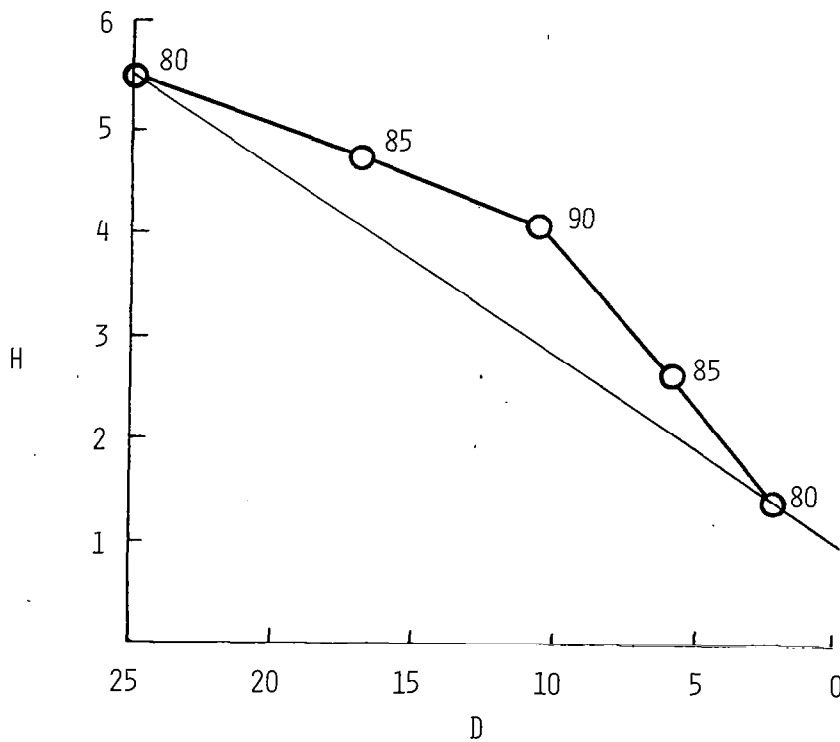Figure 8.- Application: output display at beginning of final glide.

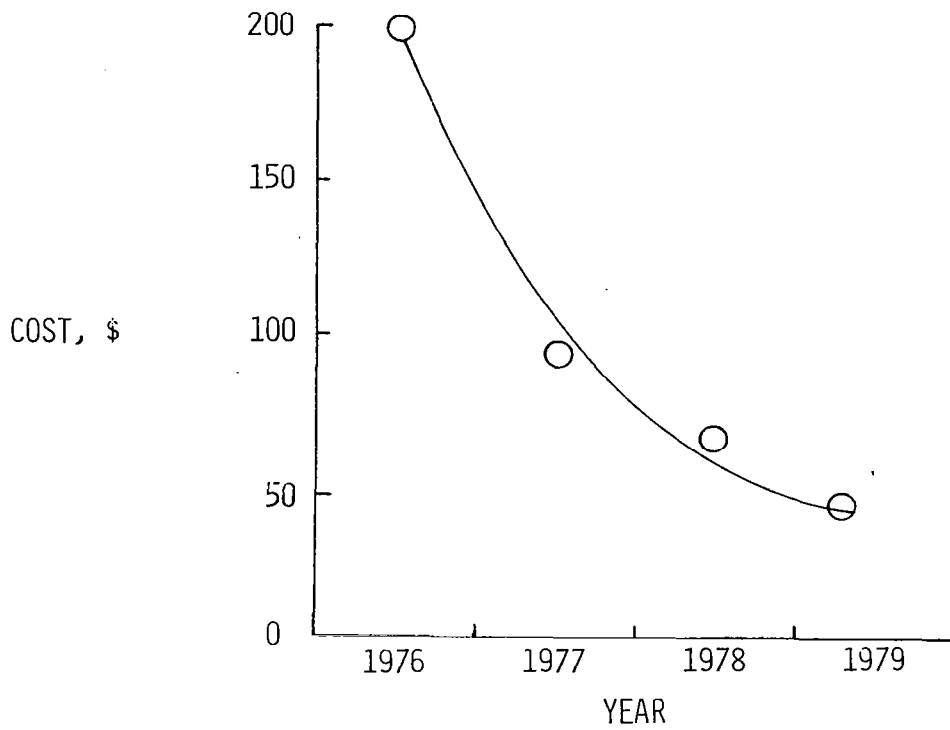Figure 9.- Application: updated output display at landmarks
during final glide.

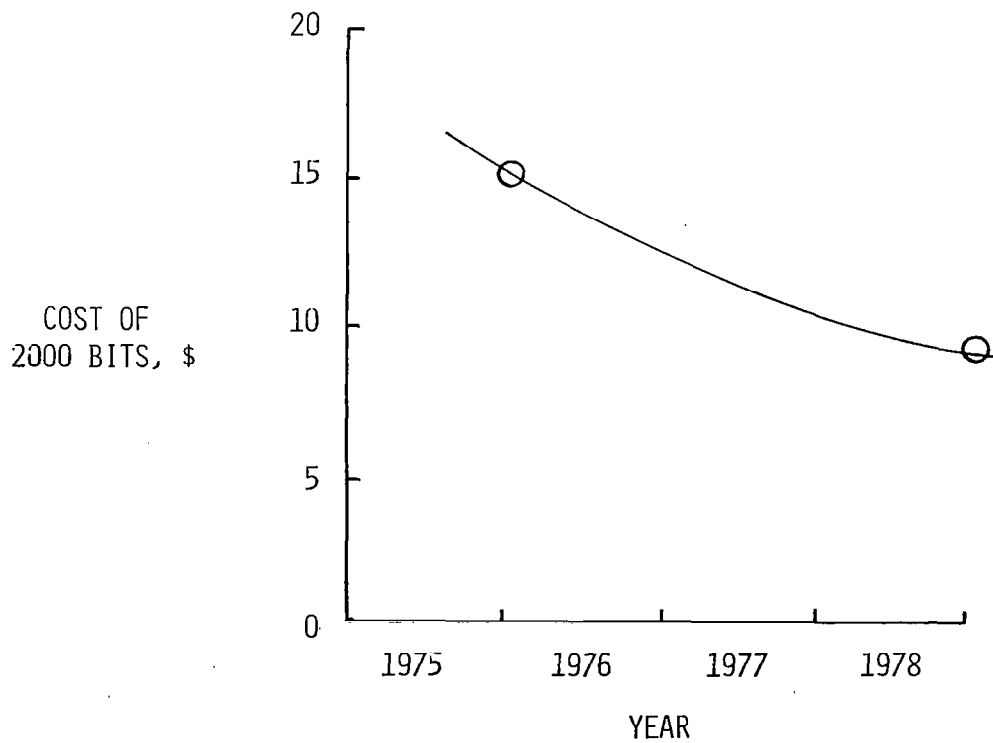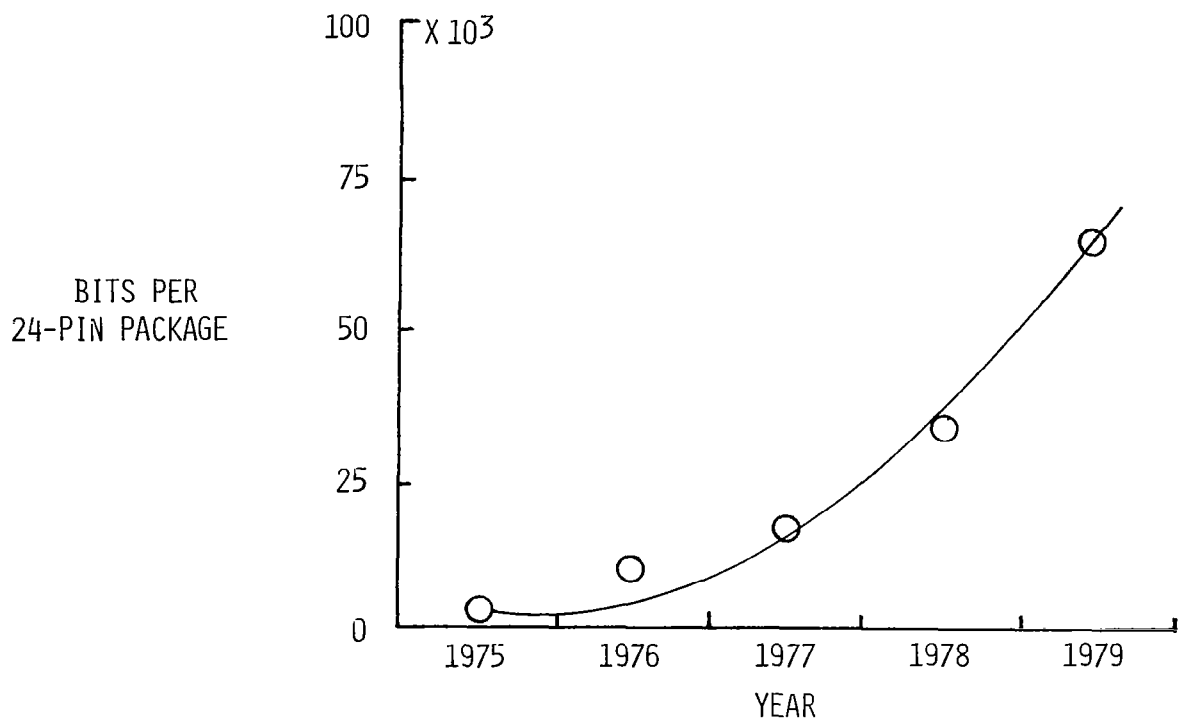Figure 10.- Cost trend of typical 16-bit microprocessor.

Figure 11.- Cost trend of RAM memory.

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Figure 12.- Trend of amount of memory per package.