# Joint University Program for Air Transportation Research - 1982

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# Joint University Program for Air Transportation Research - 1982

# NASA

National Aeronautics
and Space Administration

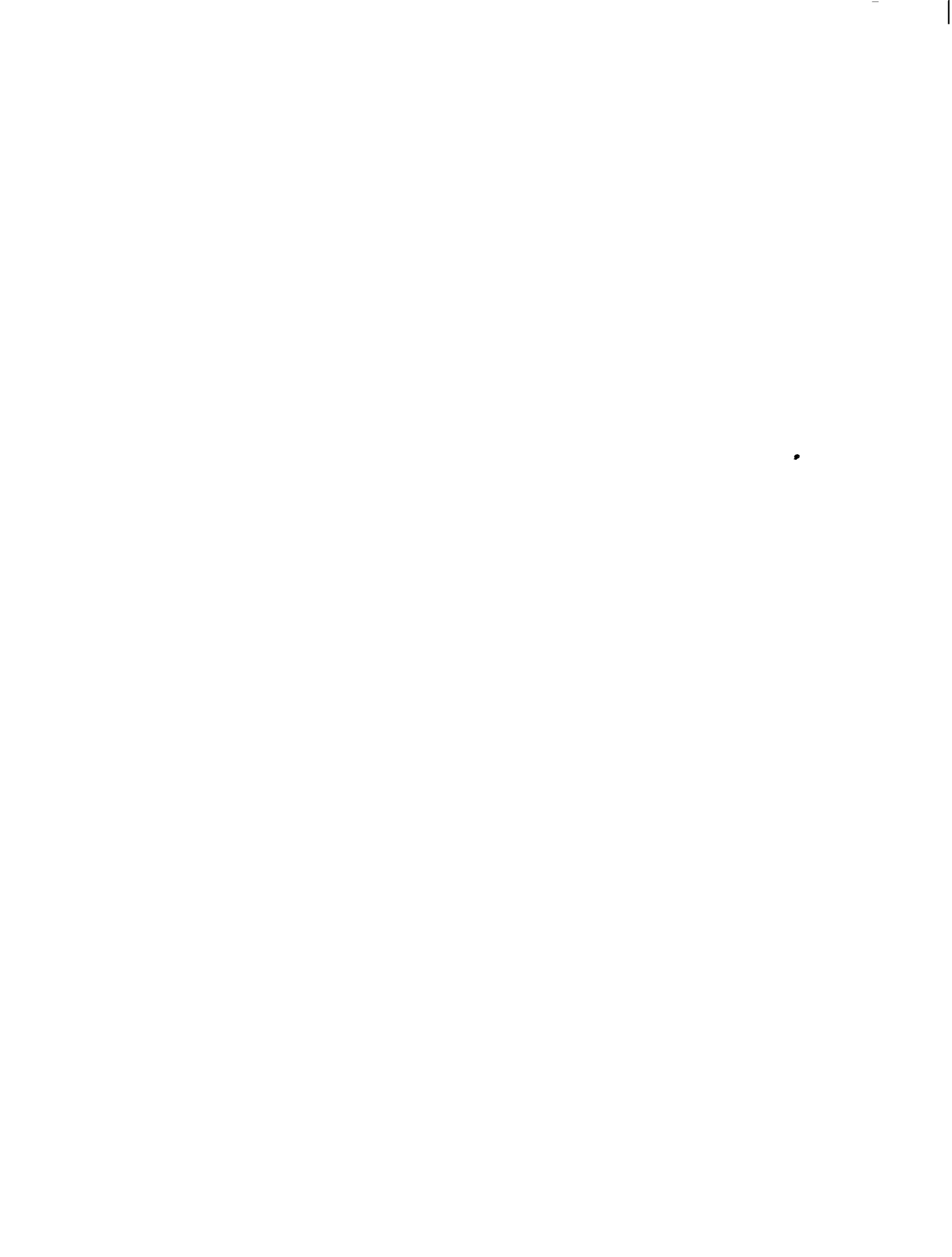Scientific and Technical
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# PREFACE

The Joint University Program for Air Transportation Research is a coordinated set of three grants sponsored by NASA Langley Research Center, one each with Massachusetts Institute of Technology (NGL-22-009-640), Ohio University (NGR-36-009-017), and Princeton University (NGL-31-001-252), to support the training of students for the air transportation system. These grants, initiated in 1971, encourage the development of innovative curriculums and support the establishment of graduate and undergraduate research assistantships and internships.

An important feature of this program is the quarterly review, one held at each of the schools and the fourth at a NASA facility. This latter review for 1982 was held at NASA Langley Research Center, Hampton, Virginia, December 10, 1982. At these reviews the program participants, both graduate and undergraduate, have an opportunity to present their research activities to their peers, professors, and invited guests from government and industry.

This conference publication represents the third in a series of yearly summaries of the activities of the program. (The 1980 summary appears in NASA CP-2176 and the 1981 summary in NASA CP-2224.) The majority of the material is the efforts of the students supported by the grants.

Three types of contributions are included. Completed works are represented by the full technical papers. Research previously published in the open literature (for example, theses or journal articles) is presented in an annotated bibliography. Status reports of ongoing research are represented by copies of viewgraphs augmented with a brief descriptive text.

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PRINCETON UNIVERSITY

# Ohio
# University

# INVESTIGATION OF AIR TRANSPORTATION TECHNOLOGY

## AT OHIO UNIVERSITY, 1982

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## INTRODUCTORY REMARKS

The work performed at Ohio University during 1982 under the Joint University Program for Air Transportation has emphasized improvement and refinement of the Loran-C receiver system for general aviation use. A major goal has been to make this receiver more suitable for use in light aircraft by a pilot who probably will not have much help in piloting and navigating. This receiver was designed earlier as a part of this NASA-supported work.

One major requirement is the capability to provide area navigation, sometimes called random navigation (RNAV). RNAV is fundamentally a computational aid which allows the pilot to select a destination point with the only restriction being availability of Loran-C signal. The destination point having been selected, the pilot should then desirably be able to proceed to that point by simply keeping a needle centered on a display. The centered needle guarantees the desired track to the destination.

A master's thesis is in preparation that provides the software and mechanization to accomplish the RNAV function. This is another step towards providing a complete Loran-C navigation receiving capability as a total result of this project effort. A preliminary paper by Oguri gives a description of the software which accomplishes the RNAV function in this Loran-C navigation system. Outputs from the calculations are cross-track error, range and tracking guidance to the waypoints, ground speed, estimated time to the waypoint, and typical CDI/To-From displays referencing the waypoints.

Work has continued on providing better preamplifier capabilities as has been traditional. Yost has worked on improving the RF receiver board to accomplish more accurate cycle tracking with an improved notch filter circuit and improved AGC. Evidence has shown that the envelope-type detector produces the same time differences as obtained from more expensive Loran-C sets such as the TI-9900 and the Trimble 10A. This is felt to be significant since the more sophisticated cycle matching techniques are considered to be of high quality.

The Ohio University receiver has been modified during this year by addition of 8K of RAM or PROM memory to aid program expansion and increase flexibility. A simpler RS-232 interface has also been added for data logging.

The display format initially had very small characters. Novacki and Nickum have provided enhanced character font graphics to improve readability of the data on the CRT. This is consistent with overall design considerations of this system for practical general aviation use.

Flight experiments have been completed; however, more are imminent now that complete repackaging of the hardware has been accomplished. Early breadboard units were found to give rise to intermittents and to reduce reliability even for experimental flights. Accordingly, considerable effort was expended to bring the hardware to a form which would increase reliability significantly. The forthcoming flights will also benefit from the new data reduction software which will speed analysis of the flight data.

It is important to stress that this receiver, which is designed for the general aviation airplane, is not to be considered an item per se for the GA marketplace; rather, it is a research receiver with considerable flexibility for examining the various parameters which must be set before the final design takes place. The intent is to provide a research tool that will aid the industry in bringing forth more optimum designs for the GA user. The industry should be able to benefit by being able to save engineering time and cost needed to produce a quality Loran-C receiving system. Evidence obtained from industrial representatives indicates that Loran-C can be expected to play an important role in the GA market of the future. The opportunity to replace a VOR navigation receiver, DME interrogator, and a dedicated RNAV computer with one Loran-C receiving system is an attractive option for the GA operator, especially if costs are kept well below the total price of the contemporary 3-unit package now running close to $8000.

The work described in the following pages has had the consistent goal especially for small aircraft. Documentation of the results for this year is contained in a short annotated bibliography. A more extensive bibliography covering earlier related work can be found in NASA CP-2224 (ref. 1).

An important highlight of the past year of the program at Ohio University has been receipt of the Radio Technical Commission for Aeronautics (RTCA) W. E. Jackson Award for the outstanding technical paper submitted in the national competition for this prize. The paper, a master's thesis, titled "A Microcomputer-Based Position Updating System for General Aviation Utilizing Loran-C," was written by Joseph P. Fischer and published in March 1982 (ref. 2). A summary of this thesis is included in the papers contributed by Ohio University to these conference proceedings. The paper provides a review of Loran-C development and operation and identifies the significance of the accuracies required with the TD's (time differences). TD's must be converted to positional information and much emphasis has been placed on accomplishing this efficiently with a specially developed algorithm. Distance and bearing angle computations are described.

The Super Jolt microcomputer was used to accomplish the calculations which ultimately were performed in flight to demonstrate finally that such devices could be effectively used to provide low cost implementation of Loran-C navigational information.

REFERENCES

1. Joint University Program for Air Transportation Research - 1982. NASA CP-2224, June 1982.

2. Fischer, Joseph P.: A Microcomputer-Based Position Updating System for General Aviation Utilizing Loran-C. OU NASA TM 85, Ohio University, May 1982.


BIBLIOGRAPHY - TECHNICAL MEMORANDA PREPARED UNDER NASA CONTRACT NGR 36-009-017

(Produced in 1982)

OU NASA
TM number


83          ENHANCED CHARACTER SIZES FOR THE VDM-1 VIDEO DISPLAY BOARD
            James D. Nickum, Stanley M. Novacki, III, December 1982.

            Described is a software program to provide increased
            character size on a 3.75-inch diagonal CRT display used in
            the Loran-C receiver designed by the Avionics Engineering
            Center at Ohio University.

84          RF FRONT-END INTERFACE AND AGC MODIFICATION
            Stephen R. Yost, December 1982.

            The Mini-L-82 RF front-end has been interfaced to the
            Ohio University Loran-C receiver utilizing a modified
            AGC system.

85          A MICROCOMPUTER-BASED POSITION UPDATING SYSTEM FOR GENERAL
            AVIATION UTILIZING LORAN-C
            Joseph P. Fischer, May 1982.

            This report identifies the advantages Loran-C offers over
            VOR/DME as a primary navigation aid. These advantages
            include long range coverage by several stations, coverage
            at low altitudes and the capability to have non-precision
            approaches at airports not already served by landing aids.
            Modern digital electronic technology is used to produce a
            device to convert Loran-C to useful pilot information using
            simple software algorithms and low-cost microprocessor
            devices. The cost and lack of availability of suitable
            processors to execute these algorithms have prevented a
            Loran-C navigator from being developed prior to this work.
            Results indicate that the microprocessor-based Loran-C
            navigator has an accuracy of 1.0 nm or less over an area
            typically covered by a triad of Loran-C stations and can
            execute a position update in less than 0.2 seconds. The
            system has been tested in 30 hours of flight and has proved
            that it can give reliable and accurate navigation information.

# A MICROCOMPUTER-BASED POSITION UPDATING SYSTEM FOR GENERAL AVIATION UTILIZING LORAN-C

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ABSTRACT

The paper, which discusses use of a microprocessor for providing navigation information from the inherent hyperbolic geometries of Loran-C, also identifies the advantages Loran-C offers over VOR/DME as a primary navigation aid. These advantages include long range coverage by several stations, coverage at low altitudes, and the capability to have non-precision approaches at airports not already served by landing aids. Modern digital electronic technology is used to produce a device to convert Loran-C data to useful pilot information using simple software algorithms and low-cost microprocessor devices. The cost and lack of availability of suitable processors to execute these algorithms have prevented a Loran-C navigator from being developed prior to this work. Results indicate that the microprocessor-based Loran-C navigator has an accuracy of 1.0 nm or less over an area typically covered by a triad of Loran-C stations and can execute a position update in less than 0.2 seconds. The system has been tested in 30 hours of flight and has proved that it can give reliable and accurate navigation information.

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# ENHANCED CHARACTER SIZES FOR THE VDM-1

## VIDEO DISPLAY BOARD

Described is a software program to provide increased
character size on a 3.75-inch diagonal CRT display
used in the Loran-C receiver designed by the
Avionics Engineering Center at Ohio University.

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I. INTRODUCTION

This technical memorandum will address a display enhancement imple-
mented on the new VDM-1 video display board that is currently installed in
the Ohio University Loran-C navigation receiver. This enhancement provides
increased character size for easier viewing of the 3.75-inch diagonal CRT
display currently being used with the Loran-C receiver. The enhancement is
purely software once the display is placed in the low resolution graphics
mode. Additionally, certain functions are possible, such as displaying a
course deviation indicator (CDI) at the bottom of the display.

## II. APPROACH

It was decided to investigate the success of artificially drawing the alpha-numeric symbols in a size more easily recognizable on the three-inch CRT at a typical viewing distance in a general aviation cockpit.

The 6847 video display driver incorporated in the Ohio University Loran-C receiver has an on-chip character generator to produce standard ASCII characters in the devices character mode [1]. Characters from this generator produce 5x7 dot cells. For purposes of experimentation and especially for ease of execution, a 6x8 dot cell was chosen to be evaluated. A sample character in the 6x8 cell is shown in Figure 1. Several of the characters using this new font aspect ratio were evaluated by storing the six 8-bit bytes that represent the dot pattern of the character in the VDM-1 video memory locations. It was determined that the increase of character size of 37% produced no appreciable readability when viewed from a distance of 3 feet. The next logical step was to produce a character font that was significantly larger than the 6x8 cell font size. To make the characters twice as large in both directions with the current memory write technique requires 32 load and store instructions and 3K bytes of memory alone to store the font definitions, which is far too awkward. A simple solution was found on examination of the 6847 data sheet. The 6847 video driver chip could be placed in a course graphics mode of 128x96 pixels per screen. In this mode writing one pixel will write an equivalent 2x2 pixel in the 256x192 high resolution graphics mode. In this manner storing a 6x8 cell font will produce a 12x16 dot graphics character. In the configuration that exists on the VDM-1 board, mode initialization switch settings are changed to set up the 128x96 course graphics mode. This character size is a 450% increase in size over the original 5x7 dot font of the on-board character generator. The readability of these characters is excellent and should provide a better information display in evaluating the Ohio University developed Loran-C receiver.



Stored 6x8 cell

Enhanced 12x16 cell size as displayed.
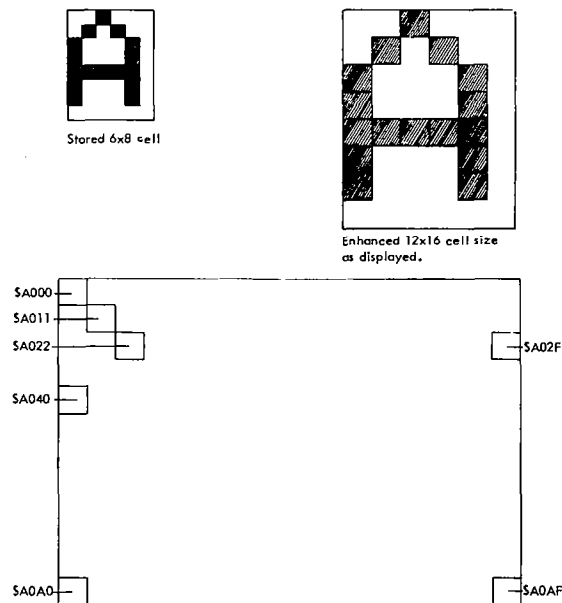
Figure 1.- Character font and display memory map.

## III. SOFTWARE

In the 128x96 dot graphics mode the video screen consists of 1536 memory locations. Each row consists of 16 8-bit-wide slices. A "1" or "0" turns each bit in a character cell on or off respectively. Each row of bits begins with a hexidecimal address on a 16-byte boundary; i.e., the first row might be $A000, the next $A010, the next $A020 and so on. To draw a character, the software routines use a two-byte address on page zero to point at the top row of the next printing location; this is conventionally called the cursor. A blank line is stored at the address contained in cursor. The cursor is incremented by $10 to point at the row beneath the one most recently written. The first byte of the character is retrieved from the font bit table and stored at the second row in the character. The cursor is advanced by $10 to point at the next row of the character font, the byte from the font table is fetched and stored and then the process repeats until all 8 of the bytes that describe the character are written at the location desired on the VDM-1 display board. In this manner, any of the printing characters in the font table can be placed in the video display field.

The font table contains all 96 of the ASCII printable characters; the remaining 32 nonprinting characters are trapped out so that nothing is printed on the screen. The non-printing characters have hexidecimal values $00-1F. By subtracting $20 from the ASCII value, the nonprinting characters can be trapped out and not printed. The remaining printable characters range from $20-$7F. Once a valid ASCII printable character is found in this range it is adjusted to the range $00-$5F which corresponds to the values in the offset address table with the same index value. This then provides the offset value to find the 8 bytes in the font table to draw the character.

The font table and offset tables for this version of the software only support the first 64 characters of the 96 printable characters. This includes the numbers, symbols, and upper case characters in the ASCII character set. The lower case letters are mapped into the upper case reference addresses for offset and font table look up. The addition of 256 more bytes of font storage would allow lower case letters to be displayed.

## IV. IMPLEMENTATION

The software implementation of this display format is accomplished using the software as listed in the appendix. Essentially, the software consists of three subroutines, two tables and a main program. The entire program as listed is intended as a subroutine with input conditions of (x) = column position on display, (y) = row position on display and (A) = ASCII character value.

The main segment of the program initializes variables and pointers and calls the subroutines to locate the character memory cell and write the character.
There are three subroutines that do the following:

Subroutine CLEAR will clear the entire screen of all characters.

Subroutine SETCSR will, based on the values in the X and Y registers, determine the cursor position in the VDM-1 display memory space to write the character. The value of X can range from $00-$0F, and the value of Y from $00-$0C.

Subroutine DRWCHR will, based on the value in the A accumulator, fetch the proper offset address value from the offset address table and then fetch and write to the screen memory the image of the values stored in the font table.

The two tables consist of the offset address table which provides the indexing based on the ASCII character value into the font table. Table two is the font table which contains the bit pattern in byte-wise form for output to the display screen.

For future implementation, the offset address table can be eliminated by a fixed multiply routine such that the index into the font table can be seen to be an integer integer multiple of 8. For example, if the 6th printable ASCII character is required, the offset necessary to fetch the character from the font table is 6x8, which is 48 or $30. This is the correct entry as shown in the offset address table in the appendix. This is expected to be implemented in the next revision of this software.

## V. SUMMARY

Presented here is a relatively simple method of implementing a more readable display for output of Loran-C navigation information to the pilot of the aircraft. The software takes advantage of hardware bit replication for producing the enhanced character size required in this application without the need for excessive memory allocation for font data storage.

## VI. REFERENCE

[1] <u>VDM-1 Video Display Board Instruction Manual</u>, Microcomputer Products Inc., Columbus, Ohio, May 30, 1981.

# VII. APPENDIX

```
     1
********************************************************************
     2                 *
     3                 *   THIS SOFTWARE WILL PRODUCE ENHANCED ALPHA-NUMERICS FOR
THE
     4                 *   VDM-1 VIDEO DISPLAY CARD INCLUDED IN THE LORAN C
RECEIVER
     5                 *   DESIGNED BY THE AVIONICS ENGINEERING CENTER AT OHIO
     6                 *   UNIVERSITY.  THE DISPLAY CONSISTS OF 12 ROWS OF 16
CHARACTERS.
     7                 *   THE DISPLAY CELL SIZE IS 12 X 16 BITS ASSUMING THE
HIGH RES
     8                 *   DISPLAY MODE OF 256 X 192.  THE VDM-1 IS ASSUMED TO BE
IN THE
     9                 *   128 X 96 LOW RESOLUTION MODE WHEN EXECUTING THIS
SOFTWARE.
    10                 *
    11
********************************************************************
    12                 *
    13                 *
    14   0000                   ORG 0
    15   0000 00 00   BITPTR  BSS 2
    16   0002 00 00   CURSOR  BSS 2
    17   0004 00      FONTST  BSS 1
    18   0005         BITS    EQU $1200        ;OFFSET ADDRESS TABLE START
    19                 *
    20                 *    MAIN PROGRAM START
    21                 *
    22   1000                  ORG $1000        ;START PROGRAM ADDRESS
    23   1000 20 11 10          JSR CLEAR        ;CLEAR SCREEN
    24   1003 A9 13            LDA =$13
    25   1005 85 04            STA FONTST        ;SET FONT PAGE #
    26   1007 00      INCHR   BRK               ;SET CHAR TO BE PLOTTED AND (X,Y)
    27   1008 20 45 10          JSR SETCSR        ;READY INDIRECT ADDRESSES
    28   100B 20 2A 10          JSR DRWCHR        ;DRAW THE CHARACTER!!!
    29   100E 4C 07 10          JMP INCHR         ;DO IT AGAIN..
    30                 *
    31                 *
    32
********************************************************************
    33                 *
    34                 *    CLEAR SCREEN SUBROUTINE
    35                 *
    36                 *    ENTRY       NONE
    37                 *
    38                 *    EXIT NONE
    39                 *
    40                 *    USES A,Y
    41                 *
    42                                                               9
********************************************************************
    43                 *
    44                 *
    45   1011         CLEAR   EQU *
    46   1011 A9 A0            LDA =$A0
    47   1013 85 03            STA CURSOR+1      ;HIGH BYTE CURSOR POSITION
    48   1015 A9 00    LOOP1   LDA =0
    49   1017 85 02            STA CURSOR        ;LOW BYTE OF CURSOR POSITION
    50   1019 A8              TAY                ;SET INDEX ADDRESS
    51   101A A9 FF            LDA =$FF           ;BLANKING FILL CHR..
    52   101C 91 02    LOOP2   STA (CURSOR),Y
    53   101E C8              INY                BUMP ;INDEX ADDRESS
    54   101F D0 FB            BNE LOOP2          ;LOOP TILL Y=0
    55   1021 E6 03            INC CURSOR+1       ;INCREMENT CURSOR OVER PAGE BOUND
    56   1023 A5 03            LDA CURSOR+1
    57   1025 C9 A8            CMP =$A8           ;TEST IF AT BOT OF DISP SCREEN
    58   1027 D0 EC            BNE LOOP1
    59   1029 60              RTS
    60                 *
```

```
  61                       *
  62
******************************************************************************
  63                       *
  64                       *     DRAW CHARACTER ROUTINE
  65                       *
  66                       *     ENTRY      A = ASCII VALUE OF CHARACTER
  67                       *
  68                       *                (CURSOR) = 16 BIT ADDRESS OF CURSOR POSITION
  69                       *
  70                       *     EXIT       NONE
  71                       *
  72                       *     USES       X,Y,A
  73                       *
  74
******************************************************************************
  75                       *
  76                       *
  77    102A          DRWCHR EQU *
  78    102A A2 08           LDX =8            ;READY FONT BYTE COUNTER
  79    102C A0 00           LDY =0            ;READY ZERO-OFFSET
  80                       *
  81    102E 81 00     PLOT  LDA (BITPTR),Y    ;GET BIT PATTERN
  82    1030 49 FF           EOR =$FF          ;LET'S GO INVERSE VIDEO
  83    1032 91 02           STA (CURSOR),Y    ;DRAW IT AT (X,Y) ON SCREEN
  84    1034 A5 02           LDA CURSOR
  85    1036 18             CLC
  86    1037 69 10           ADC =$10          ;FORM NEXT DRAWING ADDRESS
  87    1039 85 02           STA CURSOR
  88    103B 90 02           BCC NOFIX
  89    103D E6 03           INC CURSOR+1      ;ADJUST PAGE-NUMBER IF NEEDED
  90    103F          NOFIX  EQU *
  91    103F E6 00           INC BITPTR        ;POINT TO NEXT SET OF BITS
  92    1041 CA             DEX               ;COUNT BITS JUST PLOTTED
  93    1042 D0 EA           BNE PLOT          ;IF NOT DONE, PLOT REST OF CHAR
  94    1044 60       DONE  RTS
  95                       *
  96                       *
  97
******************************************************************************
  98                       *
  99                       *     SET CURSOR ROUTINE
 100                       *
 101                       *     ENTRY      X = COLUMN FOR CURSOR POSITION
 102                       *                Y = ROW FOR CURSOR POSITION
 103                       *                A = ASCII VALUE OF CHAR TO BE WRITTEN
 104                       *
 105                       *
 106                       *     EXIT       (CURSOR) = ADDRESS OF CURSOR LOCATION
 107                       *
 108                       *     USES       NONE
 109                       *
 110
******************************************************************************
 111                       *
 112                       *
 113                       *
 114    1045          SETCSR EQU *
 115    1045 48             PHA               ;SAVE CHR ON STACK
 116    1046 A9 A0           LDA =$A0
 117    1048 85 03           STA CURSOR+1
 118    104A A9 00           LDA =0
 119    104C 85 02           STA CURSOR        ;INIT CURSOR TO (0,0) ON SCREEN
 120    104E C0 00           CPY =0
 121    1050 F0 0A           BEQ ROWSET        ;NO NEED TO ADJUST CURSOR FOR
ROW..
 122    1052 18       LOCROW CLC               ;COMPUTE NEW ADDRESS FROM X,Y
COORDS
 123    1053 69 80           ADC =$80          ;MOVE TO NEXT ROW
 124    1055 90 02           BCC DECNT         ;NO NEED TO FIX PAGE OF CURSOR
 125    1057 E6 03           INC CURSOR+1      ;DO SO OTHERWISE
 126    1059 88       DECNT  DEY
```

```
127   105A DO F6          BNE LOCROW        ;LOOP UNTIL AT ROW (Y)
128   105C 85 02    ROWSET STA CURSOR
129   105E 8A             TXA               ;GET X-COORD TO ADD TO CURSOR
130   105F 29 0F          AND =$0F          ;NO COL NUMBERS > 15!
131   1061 18             CLC
132   1062 65 02          ADC CURSOR        ;ADD IN COLUMN NUMBER
133   1064 85 02          STA CURSOR        ;FORM ABSOULUTE CURSOR ADDRESS
134                *
135                *   CURSOR READY FOR PLOTTING CHARACTER..
136                *
137   1066 68             PLA               ;RECOVER CHARACTER TO COMPUTE BIT
TABLE ADD.
138   1067 48             PHA               ;SAVE IT FOR PLOTTING
139   1068 18             CLC
140   1069 E9 20          SBC =$20          ;DISALLOW CTRL CHRS; ALSO SAVES
SPACE!!
141   106B AA             TAX               ;USE CHAR AS OFFSET INTO ADDRESS
TABLE
142   106C BD 00 12       LDA BITS,X        ;GET LOW-ORDER BYTE OF FONT ENTRY
143   106F 85 00          STA BITPTR
144   1071 68             PLA               ;RECOVER TO COMPUTE WHICH BIT
TABLE
145   1072 29 40          AND =$40          ;SAVE BIT 6 FOR TABLE
DETERMINATION
146   1074 18             CLC
147   1075 2A             ROL A
148   1076 2A             ROL A
149   1077 2A             ROL A
150   1078 65 04          ADC FONTST        ;COMPUTE TABLE PAGE #, CARRY CLEAR
FROM ROL'S
151   107A 85 01          STA BITPTR+1      ;FORM ABSOLUTE FONT ENTRY POINTER
152   107C 60             RTS
153                *
154                *
155
********************************************************************************
156                *
157                *   OFFSET ADDRESS TABLE FOR NUMBERS AND SYMBOLS
158                *
159
********************************************************************************
160                *
161                *
162   1200               ORG $1200         .
163   1200 00            HEX 00
164   1201 08            HEX 08
165   1202 10            HEX 10
166   1203 18            HEX 18
167   1204 20            HEX 20
168   1205 28            HEX 28
169   1206 30            HEX 30
170   1207 38            HEX 38
171   1208 40            HEX 40
172   1209 48            HEX 48
173   120A 50            HEX 50
174   120B 58            HEX 58
175   120C 60            HEX 60
176   120D 68            HEX 68
177   120E 70            HEX 70
178   120F 78            HEX 78
179   1210 80            HEX 80
180   1211 88            HEX 88
181   1212 90            HEX 90
182   1213 98            HEX 98
183   1214 A0            HEX A0
184   1215 A8            HEX A8
185   1216 B0            HEX B0
186   1217 B8            HEX B8
187   1218 C0            HEX C0
188   1219 C8            HEX C8
189   121A D0            HEX D0
190   121B D8            HEX D8
```

```
191   121C E0                    HEX  E0
192   121D E8                    HEX  E8
193   121E F0                    HEX  F0
194   121F F8                    HEX  F8
195                    *
196                    *
197
********************************************************************
198                    *
199                    *   OFFSET ADDRESS TABLE FOR UPPER CASE CHARACTERS
200                    *
201
********************************************************************
202                    *
203                    *
204   1220 00                    HEX  00
205   1221 08                    HEX  08
206   1222 10                    HEX  10
207   1223 18                    HEX  18
208   1224 20                    HEX  20
209   1225 28                    HEX  28
210   1226 30                    HEX  30
211   1227 38                    HEX  38
212   1228 40                    HEX  40
213   1229 48                    HEX  48
214   122A 50                    HEX  50
215   122B 58                    HEX  58
216   122C 60                    HEX  60
217   122D 68                    HEX  68
218   122E 70                    HEX  70
219   122F 78                    HEX  78
220   1230 80                    HEX  80
221   1231 88                    HEX  88
222   1232 90                    HEX  90
223   1233 98                    HEX  98
224   1234 A0                    HEX  A0
225   1235 A8                    HEX  A8
226   1236 B0                    HEX  B0
227   1237 B8                    HEX  B8
228   1238 C0                    HEX  C0
229   1239 C8                    HEX  C8
230   123A D0                    HEX  D0
231   123B D8                    HEX  D8
232   123C E0                    HEX  E0
233   123D E8                    HEX  E8
234   123E F0                    HEX  F0
235   123F F8                    HEX  F8
236                    *
237                    *
238
********************************************************************
239                    *
240                    *   CHARACTER FONT TABLE FOR NUMBERS AND SYMBOLS
241                    *
242
********************************************************************
243                    *
244                    *
245   1300                       ORG  $1300
246   1300 00 00 00   SP         HEX  00,00,00,00,00,00,00,00
           00 00 00
           00 00
247   1308 20 20 20   XCL        HEX  20,20,20,20,00,20,20,00
           20 00 20
           20 00
248   1310 50 50 50   DQOU       HEX  50,50,50,00,00,00,00,00
           00 00 00
           00 00
249   1318 50 50 F8   LBS        HEX  50,50,F8,50,F8,50,50,00
           50 F8 50
           50 00
250   1320 20 78 A0   DOLR       HEX  20,78,A0,70,28,F0,20,00
```

```
                  70 28 F0
                  20 00
        251  1328 C0 C8 10  PRCNT  HEX C0,C8,10,20,40,98,18,00
                  20 40 98
                  18 00
        252  1330 40 A0 A0  ANDSN  HEX 40,A0,A0,40,A8,90,68,00
                  40 A8 90
                  68 00
        253  1338 20 20 20  APOS   HEX 20,20,20,00,00,00,00,00
                  00 00 00
                  00 00
        254  1340 20 40 80  LPAREN HEX 20,40,80,80,80,40,20,00
                  80 80 40
                  20 00
        255  1348 20 10 08  RPAREN HEX 20,10,08,08,08,10,20,00
                  08 08 10
                  20 00
        256  1350 20 A8 70  ASTRSK HEX 20,A8,70,20,70,A8,20,00
                  20 70 A8
                  20 00
        257  1358 00 20 20  PLUSSN HEX 00,20,20,78,20,20,00,00
                  78 20 20
                  00 00
        258  1360 00 00 00  COMMA  HEX 00,00,00,00,20,20,40,00
                  00 20 20
                  40 00
        259  1368 00 00 00  PERIOD HEX 00,00,00,00,20,20,00,00
                  00 20 20
                  00 00
        260  1370 00 08 10  OSLASH HEX 00,08,10,20,40,80,00,00
                  20 40 80
                  00 00
        261  1378 70 88 98  ZERO   HEX 70,88,98,A8,C8,88,70,00
                  A8 C8 88
                  70 00
        262  1380 20 60 20  ONE    HEX 20,60,20,20,20,20,70,00
                  20 20 20
                  70 00
        263  1388 70 88 08  TWO    HEX 70,88,08,70,80,80,F8,00
                  70 80 80
                  F8 00
        264  1390 F8 08 10  THREE  HEX F8,08,10,30,08,88,70,00
                  30 08 88
                  70 00
        265  1398 10 30 50  FOUR   HEX 10,30,50,F8,10,10,10,00
                  F8 10 10
                  10 00
        266  13A0 F8 80 F0  FIVE   HEX F8,80,F0,08,08,88,70,00
                  08 08 88
                  70 00
        267  13A8 38 40 80  SIX    HEX 38,40,80,F0,88,88,70,00
                  F0 88 88
                  70 00
        268  13B0 F8 08 08  SEVEN  HEX F8,08,08,10,20,40,80,00
                  10 20 40
                  80 00
        269  13B8 70 88 88  EIGHT  HEX 70,88,88,70,88,88,70,00
                  70 88 88
                  70 00
        270  13C0 70 88 88  NINE   HEX 70,88,88,78,08,10,E0,00
                  78 08 10
                  E0 00
        271  13C8 00 00 20  COLON  HEX 00,00,20,00,20,00,00,00
                  00 20 00
                  00 00
        272  13D0 00 00 20  SEM    HEX 00,00,20,00,20,20,40,00
                  00 20 20
                  40 00
        273  13D8 10 20 40  LTHAN  HEX 10,20,40,80,40,20,10,00
                  80 40 20
                  10 00
        274  13E0 00 00 F8  EQALS  HEX 00,00,F8,00,F8,00,00,00
```

```
                    00 F8 00
                    00 00
 275    13E8 40 20 10     GTHAN    HEX 40,20,10,08,10,20,40,00
                    08 10 20
                    40 00
 276    13F0 70 88 08     QUESTN   HEX 70,88,08,30,20,00,20,00
                    30 20 00
                    20 00
 277    13F8 70 88 A8     ATSIGN   HEX 70,88,A8,B8,B0,80,78,00
                    B8 B0 80
                    78 00
 278                      *
 279                      *
 280
*****************************************************************************
 281                      *
 282                      *     CHARACTER FONT TABLE FOR UPPER CASE LETTERS
 283                      *
 284
*****************************************************************************
 285                      *
 286                      *
 287    1400 20 50 88     CAPA     HEX 20,50,88,88,F8,88,88,00
                    88 F8 88
                    88 00
 288    1408 F0 88 88     CAPB     HEX F0,88,88,F0,88,88,F0,00
                    F0 88 88
                    F0 00
 289    1410 70 88 80     CAPC     HEX 70,88,80,80,80,88,70,00
                    80 80 88
                    70 00
 290    1418 F0 88 88     CAPD     HEX F0,88,88,88,88,88,F0,00
                    88 88 88
                    F0 00
 291    1420 F8 80 80     CAPE     HEX F8,80,80,F0,80,80,F8,00
                    F0 80 80
                    F8 00
 292    1428 F8 80 80     CAPF     HEX F8,80,80,F0,80,80,80,00
                    F0 80 80
                    80 00
 293    1430 70 88 80     CAPG     HEX 70,88,80,80,90,88,78,00
                    80 90 88
                    78 00
 294    1438 88 88 88     CAPH     HEX 88,88,88,F8,88,88,88,00
                    F8 88 88
                    88 00
 295    1440 70 20 20     CAP I    HEX 70,20,20,20,20,20,70,00
                    20 20 20
                    70 00
 296    1448 08 08 08     CAP J    HEX 08,08,08,08,08,88,70,00
                    08 08 88
                    70 00
 297    1450 88 90 A0     CAPK     HEX 88,90,A0,C0,A0,90,88,00
                    C0 A0 90
                    88 00
 298    1458 80 80 80     CAP L    HEX 80,80,80,80,80,80,F8,00
                    80 80 80
                    F8 00
 299    1460 88 B8 A8     CAPM     HEX 88,B8,A8,A8,A8,88,88,00
                    A8 A8 88
                    88 00
 300    1468 88 80 C8     CAPN     HEX 88,80,C8,A8,98,88,88,00
                    A8 98 88
                    88 00
 301    1470 70 88 88     CAPO     HEX 70,88,88,88,88,88,70,00
                    88 88 88
                    70 00
 302    1478 F0 88 F8     CAPP     HEX F0,88,F8,F0,80,80,80,00
                    F0 80 80
                    80 00
 303    1480 70 88 88     CAPQ     HEX 70,88,88,88,A8,90,68,00
                    88 A8 90
```

```
                  68 00
     304    1488  F0 88 88   CAPR    HEX  F0,88,88,F0,A0,90,88,00
                  F0 A0 90
                  88 00
     305    1490  70 88 80   CAPS    HEX  70,88,80,70,08,88,70,00
                  70 08 88
                  70 00
     306    1498  F8 A8 20   CAPT    HEX  F8,A8,20,20,20,20,20,00
                  20 20 20
                  20 00
     307    14A0  88 88 88   CAPU    HEX  88,88,88,88,88,88,70,00
                  88 88 88
                  70 00
     308    14A8  88 88 88   CAPV    HEX  88,88,88,A0,A0,20,20,00
                  A0 A0 20
                  20 00
     309    14B0  88 88 88   CAPW    HEX  88,88,88,A8,A8,A8,50,00
                  A8 A8 A8
                  50 00
     310    14B8  88 88 50   CAPX    HEX  88,88,50,20,50,88,88,00
                  20 50 88
                  88 00
     311    14C0  88 88 50   CAPY    HEX  88,88,50,20,20,20,20,00
                  20 20 20
                  20 00
     312    14C8  F8 08 10   CAPZ    HEX  F8,08,10,20,40,80,F8,00
                  20 40 80
                  F8 00
     313    14D0  F8 C0 C0   LBRKT   HEX  F8,C0,C0,C0,C0,C0,F8,00
                  C0 C0 C0
                  F8 00
     314    14D8  00 80 40   LSLSH   HEX  00,80,40,20,10,08,00,00
                  20 10 08
                  00 00
     315    14E0  F8 18 18   RBRKT   HEX  F8,18,18,18,18,18,F8,00
                  18 18 18
                  F8 00
     316    14E8  20 50 81   CARET   HEX  20,50,81,00,00,00,00,00
                  00 00 00
                  00 00
     317    14F0  00 00 00   USCORE  HEX  00,00,00,00,00,00,F8,00
                  00 00 00
                  F8 00
     318                             END

END PASS 2:    0 ERRORS

1 SYMB   ADDR  DEF    REFERENCES

ANDSN   1330   252
APOS    1338   253
ASTRSK  1350   256
ATSIGN  13F8   277
BITPTR  0000    15      91    143    151    81
BITS    1200    18     142
CAPA    1400   287
CAPB    1408   288
CAPC    1410   289
CAPD    1418   290
CAPE    1420   291
CAPF    1428   292
CAPG    1430   293
CAPH    1438   294
CAPI    1440   295
CAPJ    1448   296
CAPK    1450   297
CAPL    1458   298
CAPM    1460   299
CAPN    1468   300
CAPO    1470   301
CAPP    1478   302
CAPQ    1480   303
```

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CAPR | 1488 | 304 | | | | | | | | | | |
| CAPS | 1490 | 305 | | | | | | | | | | |
| CAPT | 1498 | 306 | | | | | | | | | | |
| CAPU | 14A0 | 307 | | | | | | | | | | |
| CAPV | 14A8 | 308 | | | | | | | | | | |
| CAPW | 14B0 | 309 | | | | | | | | | | |
| CAPX | 14B8 | 310 | | | | | | | | | | |
| CAPY | 14C0 | 311 | | | | | | | | | | |
| CAPZ | 14C8 | 312 | | | | | | | | | | |
| CARET | 14E8 | 316 | | | | | | | | | | |
| CLEAR | 1011 | 45 | 23 | | | | | | | | | |
| COLON | 13C8 | 271 | | | | | | | | | | |
| COMMA | 1360 | 258 | | | | | | | | | | |
| CURSOR | 0002 | 16 | 47 | 49 | 55 | 56 | 84 | 87 | 89 | 117 | 119 | 125 |
| | | | 128 | 132 | 133 | 52 | 83 | | | | | |
| DECNT | 1059 | 126 | 124 | | | | | | | | | |
| DOLR | 1320 | 250 | | | | | | | | | | |
| DONE | 1044 | 94 | | | | | | | | | | |
| DQOU | 1310 | 248 | | | | | | | | | | |
| DRWCHR | 102A | 77 | 28 | | | | | | | | | |
| EIGHT | 13B8 | 269 | | | | | | | | | | |
| EQALS | 13E0 | 274 | | | | | | | | | | |
| FIVE | 13A0 | 266 | | | | | | | | | | |
| FONTST | 0004 | 17 | 25 | 150 | | | | | | | | |
| FOUR | 1398 | 265 | | | | | | | | | | |
| GTHAN | 13E8 | 275 | | | | | | | | | | |
| INCHR | 1007 | 26 | 29 | | | | | | | | | |
| LBRKT | 14D0 | 313 | | | | | | | | | | |
| LBS | 1318 | 249 | | | | | | | | | | |
| LOCROW | 1052 | 122 | 127 | | | | | | | | | |
| LOOP1 | 1015 | 48 | 58 | | | | | | | | | |
| LOOP2 | 101C | 52 | 54 | | | | | | | | | |
| LPAREN | 1340 | 254 | | | | | | | | | | |
| LSLSH | 14D8 | 314 | | | | | | | | | | |
| LTHAN | 13D8 | 273 | | | | | | | | | | |
| NINE | 13C0 | 270 | | | | | | | | | | |
| NOFIX | 103F | 90 | 88 | | | | | | | | | |
| ONE | 1380 | 262 | | | | | | | | | | |
| OSLASH | 1370 | 260 | | | | | | | | | | |
| PERIOD | 1368 | 259 | | | | | | | | | | |
| PLOT | 102E | 81 | 93 | | | | | | | | | |
| PLUSSN | 1358 | 257 | | | | | | | | | | |
| PRCNT | 1328 | 251 | | | | | | | | | | |
| QUESTN | 13F0 | 276 | | | | | | | | | | |
| RBRKT | 14E0 | 315 | | | | | | | | | | |
| ROWSET | 105C | 128 | 121 | | | | | | | | | |
| RPAREN | 1348 | 255 | | | | | | | | | | |
| SEM | 13D0 | 272 | | | | | | | | | | |
| SETCSR | 1045 | 114 | 27 | | | | | | | | | |
| SEVEN | 13B0 | 268 | | | | | | | | | | |
| SIX | 13A8 | 267 | | | | | | | | | | |
| SP | 1300 | 246 | | | | | | | | | | |
| THREE | 1390 | 264 | | | | | | | | | | |
| TWO | 1388 | 263 | | | | | | | | | | |
| USCORE | 14F0 | 317 | | | | | | | | | | |
| XCL | 1308 | 247 | | | | | | | | | | |
| ZERO | 1378 | 261 | | | | | | | | | | |

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TECHNICAL MEMORANDUM OU NASA 84

# RF FRONT END INTERFACE AND AGC MODIFICATION

The Mini-L-82 RF front end has been interfaced to the
Ohio University LORAN-C receiver utilizing a modified
AGC system.

Stephen R. Yost

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# I. INTRODUCTION

The latest RF front end built by Burhans (Mini-L-82) has been successfully interfaced to the Ohio University LORAN-C receiver (Figure 1). In order for the front end to operate optimally, modifications were made to existing automatic gain control (AGC) circuitry already developed for the Ohio University LORAN-C receiver. This AGC circuit is described in reference 1. This technical memorandum will describe the hardware modifications to the AGC and other interface circuitry, as well as some preliminary results.

# II. RF FRONT END DESCRIPTION

The Mini-L-82 RF front end (refer to Figures 2 and 3) is similar in overall design to the previous front end used with the Ohio University receiver but it has a much narrower bandwidth. Also, the Mini-L-82 has a much improved response to lower input signal levels. The output of the front end is a negative-going zero crossing pulse which is 10 microseconds long (Figure 4). In order for the receiver to operate properly, this pulse is inverted using a 7404 TTL inverter. The front end output is also open collector; therefore, an external pull-up resistor is provided. The positive-going 10 microsecond pulse is applied to the existing receiver circuitry which extends the pulse to 70 microseconds using a 74123 monostable. This 70-microsecond pulse is the optimum value for the search and track software routines. Efforts were made to adjust search and track software parameters to use the 10-microsecond pulse. However, it was found that this pulse width increased search time substantially and also created difficulties for the tracking loops because of the LORAN-C phase code which causes the zero crossing pulse to shift five microseconds with each phase reversal. Therefore, the interface between the Mini-L-82 and the receiver is essentially the same as that for the old front end.

# III. AGC CIRCUIT DESIGN

The AGC circuit is based roughly on the circuit designed for use with the old front end (ref. 2), and is part of the sensor processor section of the Ohio University LORAN-C receiver (Figures 5 to 7). The envelopes of all the tracked LORAN-C stations are sampled individually with the sampled voltages stored on capacitors. Each tracked station has its own "channel" in the AGC circuit (Figure 8). Channel address control is provided by the microcomputer. Since the magnitude of the sampled voltage often exceeds five volts, all of the AGC circuit components are CMOS integrated circuits with a twelve-volt power supply.

Even though the basic circuit design is similar to the previous AGC circuit, there are important differences to optimize performance with the new front end. The front end is designed to optimize performance at low signal levels. The AGC will "turn down" the gain on the LORAN-C stations until the region of best front end performance is reached. Since the various LORAN-C stations in a given chain are received at various signal amplitudes, it is the function of the AGC to reduce the gain on each

station proportionate to that station's received signal level. The end result is that all of the LORAN-C stations are processed at a constant signal level. This condition is essential to the proper operation of an envelope-detector front end such as the Mini-L-82.

In the previous AGC circuit, the envelope was sampled during a 20-microsecond sampling window that was delayed 40 microseconds from the zero crossing. It was determined that this sampling area could possibly contain some sky wave contamination. In the current AGC design, the envelope is sampled during a 20-microsecond window starting at the zero crossing. The sampled voltage is dependent on the slope of the envelope at that point. Strong stations have a large slope; hence, a larger sample voltage is stored for that station. The sampled voltages are stored on their respective channels and adjusted for optimum front end performance by the gain and offset adjustment op-amp in the circuit. The AGC amplifier is an integral part of the Mini-L-82 front end design and provides up to 60 dB of gain.

The AGC circuit was built on a Vector (tm) circuit card in the receiver that also contains 8K bytes of ROM/RAM memory and the serial interface (Figures 9, 10, and 11). Tantalum capacitors were used for the sample and hold circuits because of their low leakage characteristic.

## IV. RESULTS AND FURTHER OPTIMIZATION

Preliminary results indicate that the new front end AGC combination perform satisfactorily. Side-by-side bench tests with Trimble 10A and Texas Instruments 9900 LORAN-C receivers have proven that the proper time differences are being obtained. Extensive bench tests and flight tests will follow as time permits.

Further optimization of the AGC circuit will occur as software to track all of the stations in a LORAN-C chain is developed. The AGC circuit was designed to sample up to six separate LORAN-C stations. Along with expanded station tracking software, a more sophisticated search routine is also under development. It is also planned to develop a printed circuit board for the AGC and enclose it with the RF front end in a sealed enclosure to reduce interference from the other digital circuits of the microcomputer.

## V. ACKNOWLEDGEMENTS

## VI. REFERENCES

1.  Yost, Stephen R., "Commutated Automatic Gain Control System",
    OU NASA TM-81, Avionics Engineering Center, Department of Electrical
    Engineering, Ohio University, Athens, Ohio, 45701, November 1981.

2.  Lilley, Dr. R.W. and Daryl McCall, "A LORAN-C Prototype Navigation
    Receiver for General Aviation", OU NASA TM-80, Avionics Engineering
    Center, Department of Electrical Engineering, Ohio University, Athens,
    Ohio, 45701, August 1981.
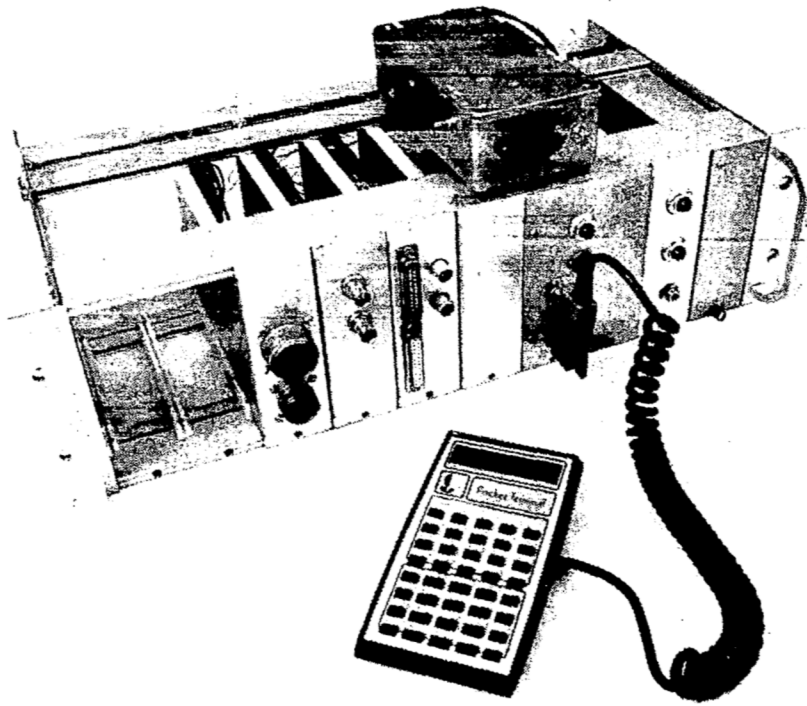
Figure 1.- Ohio University Loran-C receiver.
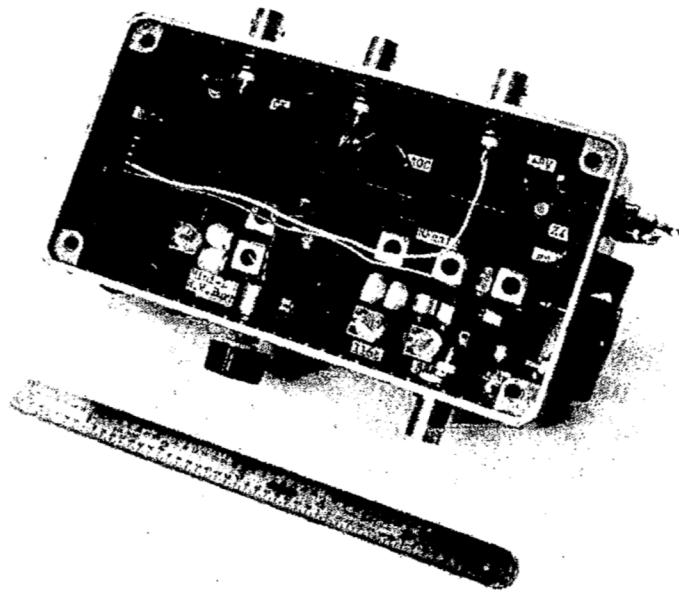


Figure 2.- Mini-L-82 front end.

Figure 3.- Mini-L-82 circuit diagram.

LORAN CHAIN
GRI = 99,600μS

LORAN STATION
PULSE SPACING =
1000μS

LORAN ENVELOPE
ZERO CROSSING
PULSE = 10μS

ZERO CROSSING
PULSE AND
SOFTWARE
EQUALS PULSE
(LENGTH = 1μS)
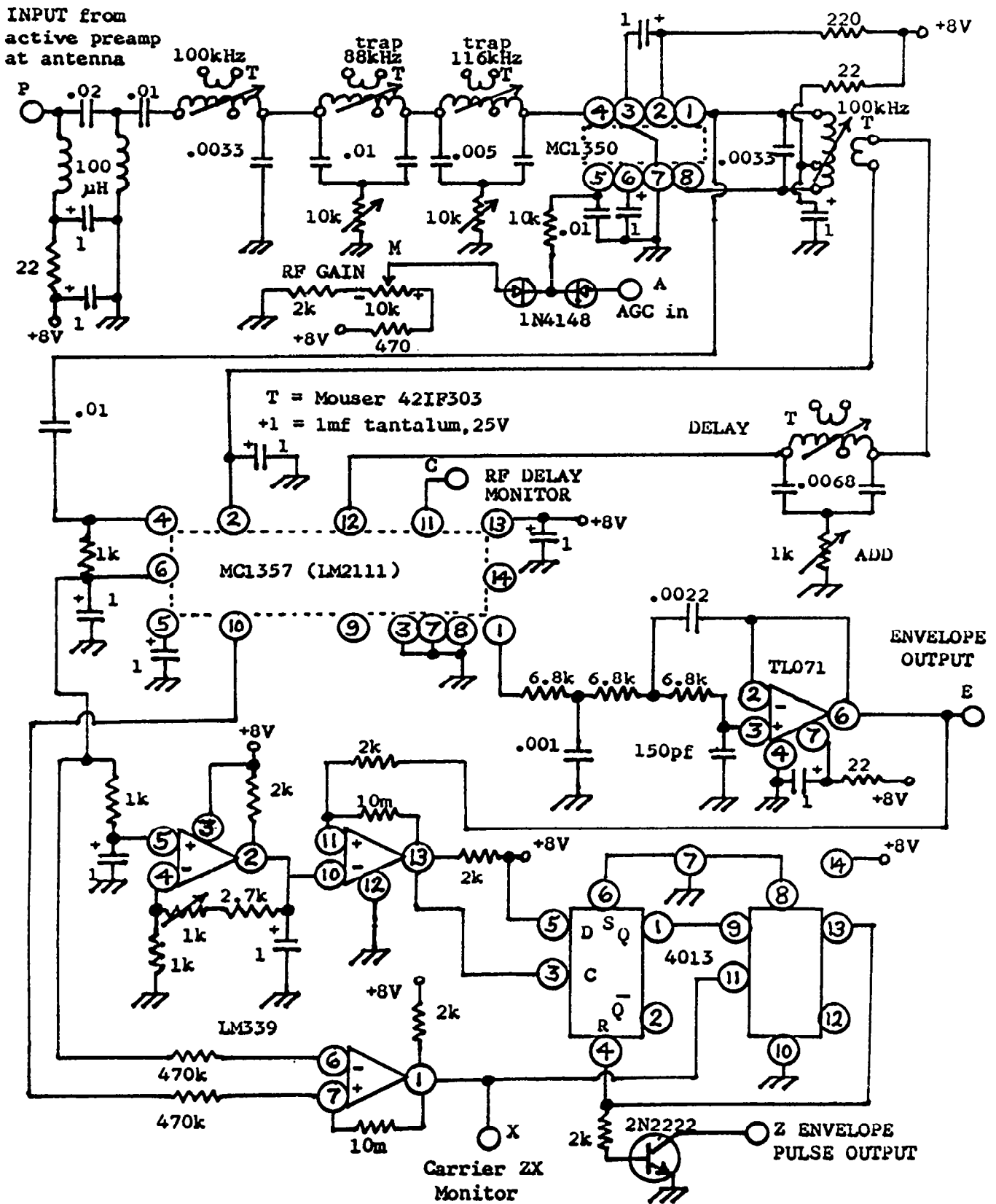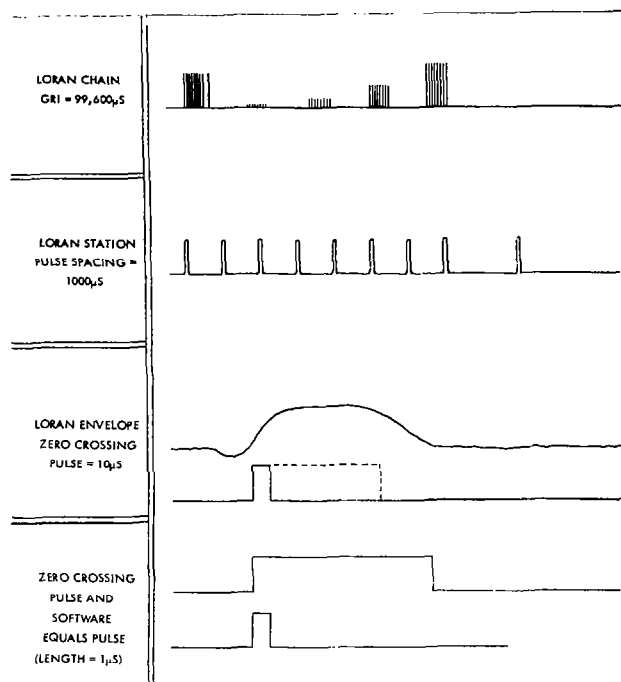
Figure 4.- Loran-C chain parameters.
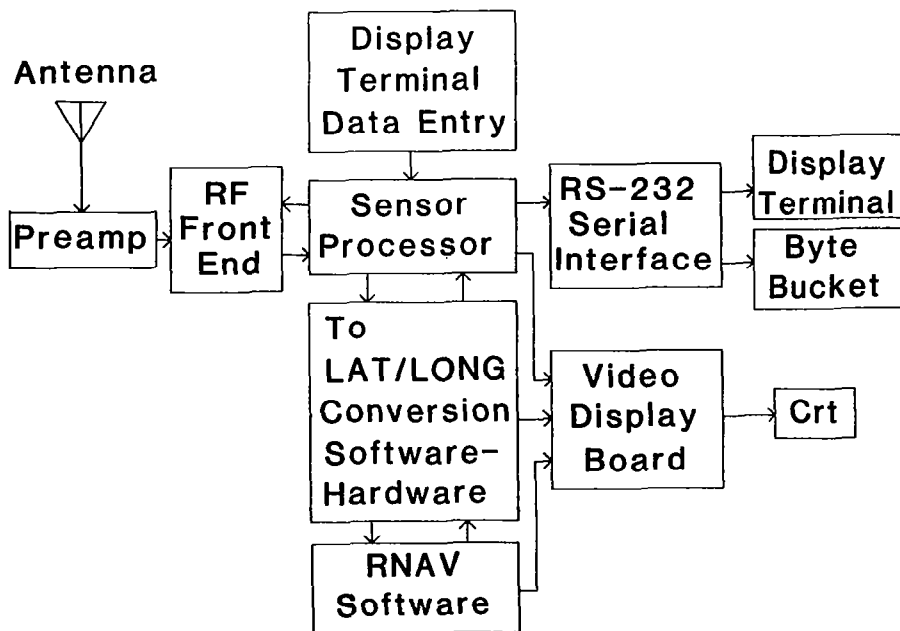


Figure 5.- Receiver block diagram.
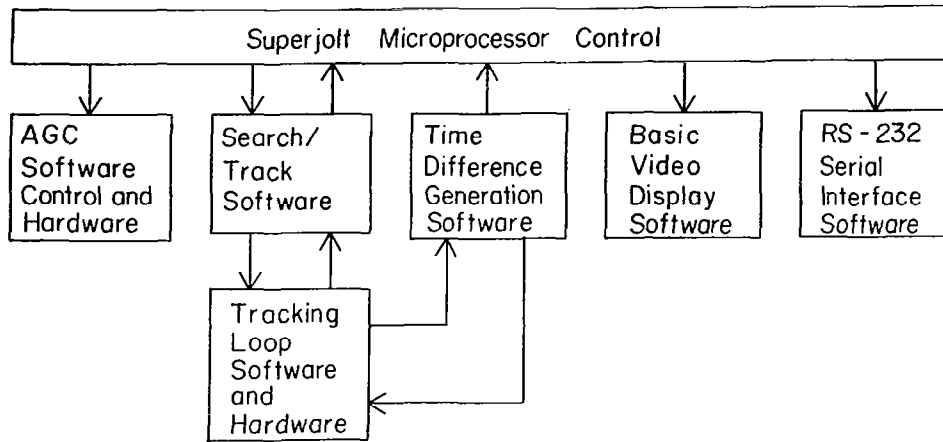
Figure 6.- Sensor processor block diagram.
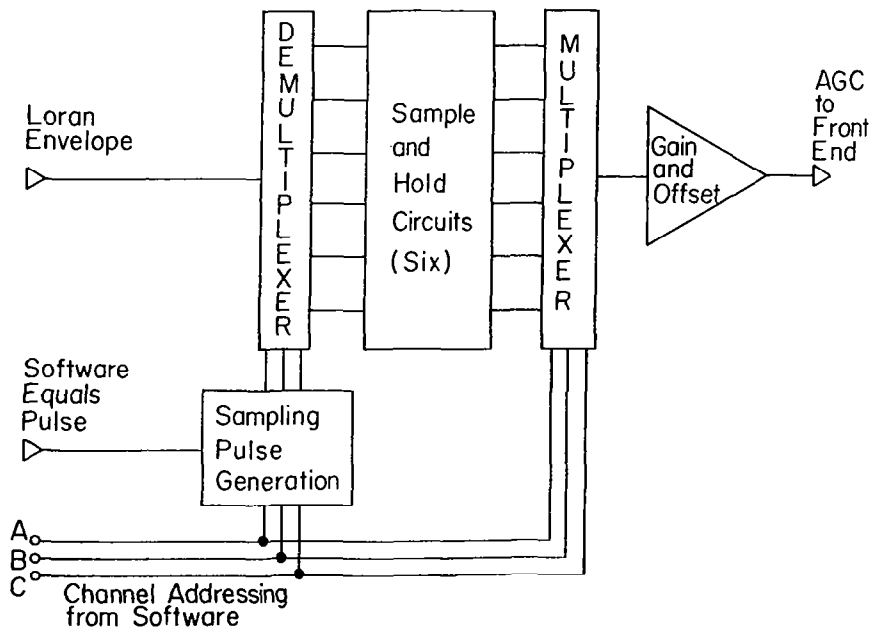


Figure 7.- AGC block diagram.
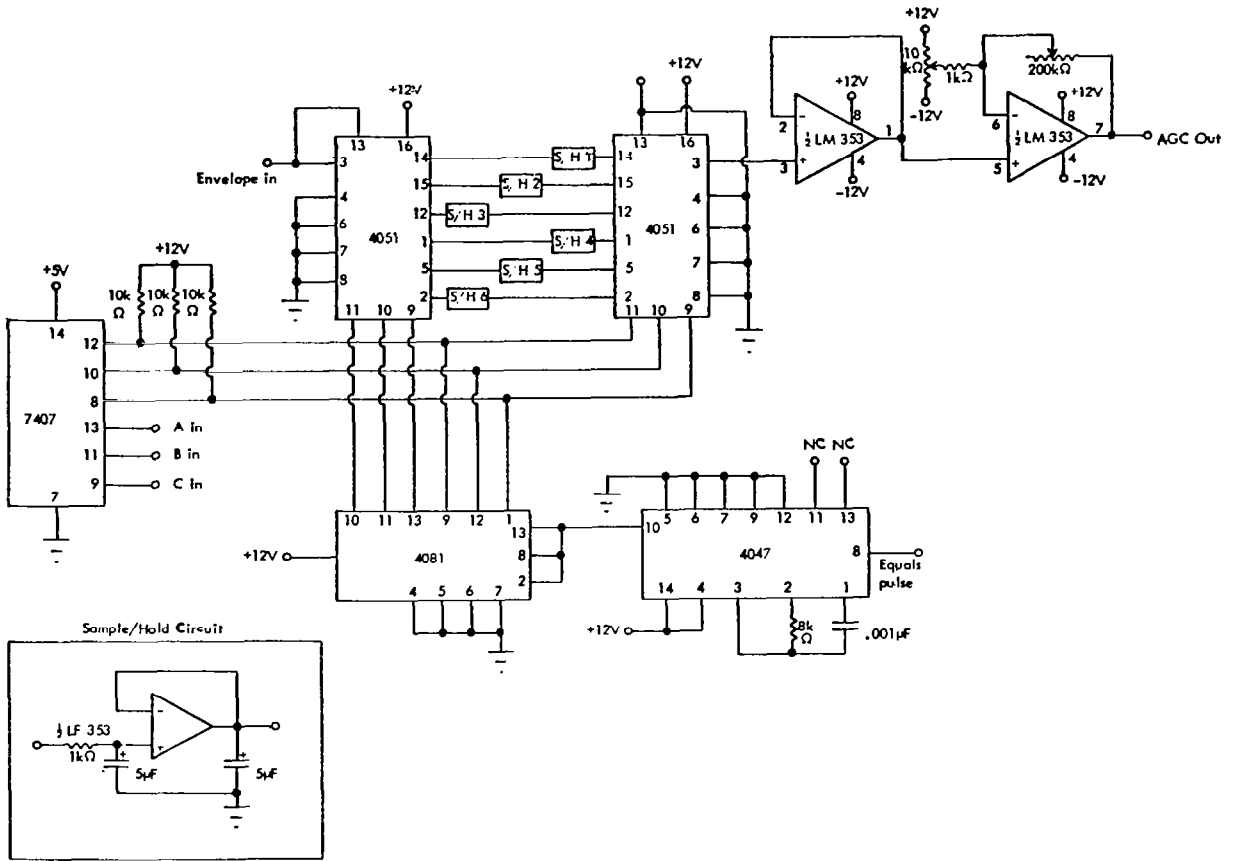
Figure 8.- AGC circuit diagram.
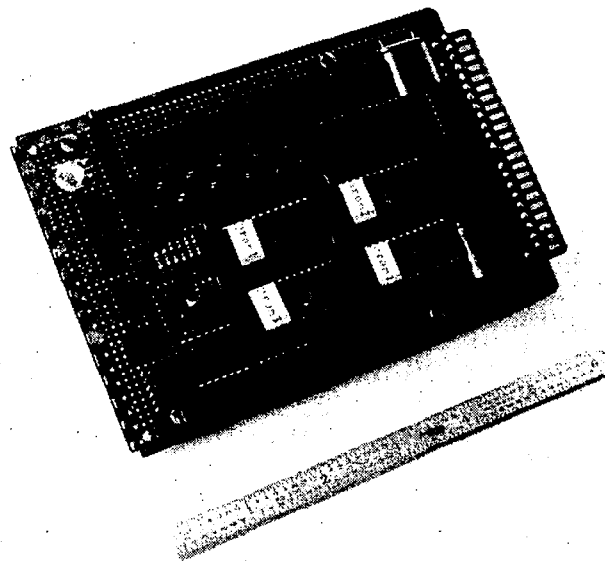


Figure 9.- AGC/memory/interface board.
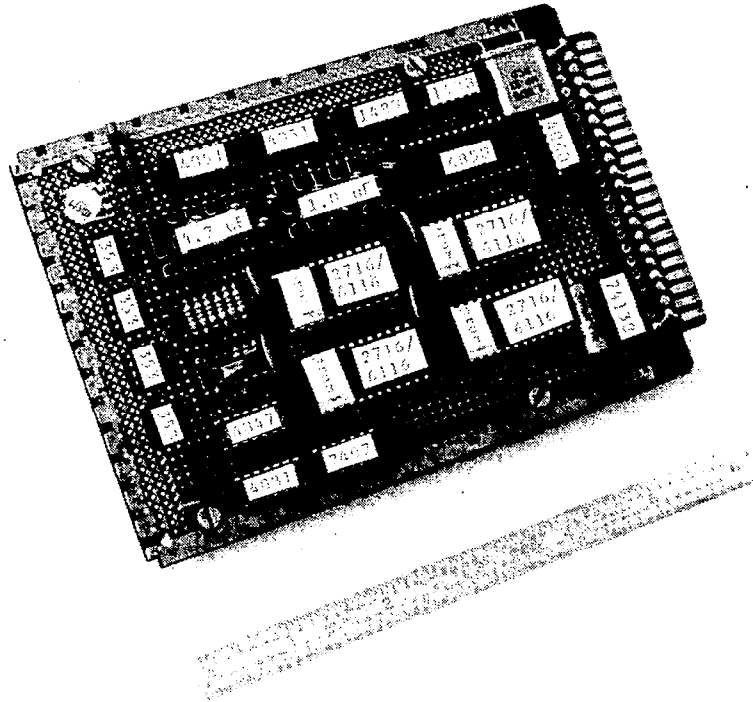
Figure 10.- AGC/memory/interface board components.



| | | | | |
|---|---|---|---|---|
| | Ground | 1 | A | |
| | D0 | 2 | B | Ground |
| | D1 | 3 | C | -12V |
| | D2 | 4 | D | A0 |
| Data | D3 | 5 | E | A1 |
| Buss | D4 | 6 | F | A2 |
| | D5 | 7 | H | A3 |
| | D6 | 8 | J | A4 |
| | D7 | 9 | K | A5 |
| | Reset | 10 | L | A6 |
| Control | 02 clock | 11 | M | A7 |
| Buss | R/W̄ | 12 | N | A8 |
| | R/W* | 13 | P | A9 |
| | Equals pulse | 14 | R | A10 |
| | Envelope | 15 | S | A11 |
| | AGC | 16 | T | A12 |
| | Control A | 17 | U | A13 |
| | Control B | 18 | V | A14 |
| | Control C | 19 | W | A15 |
| | | 20 | X | |
| | | 21 | Y | +12V |
| | +5V | 22 | Z | +5V |

Address Buss (spanning A0–A15)
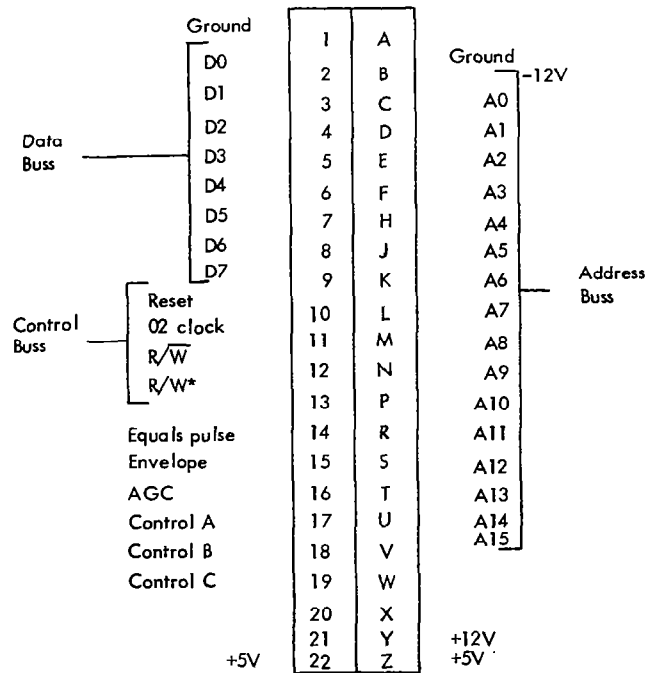
Figure 11.- Edge connector pin assignments.

# PRELIMINARY DESCRIPTION OF THE

# AREA NAVIGATION SOFTWARE FOR A

# MICROCOMPUTER-BASED LORAN-C RECEIVER

This area navigation software gives automatic capability to the Ohio University Loran-C receiver based on a microprocessor (MOS 6502).

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I.   INTRODUCTION

This report describes engineering work which has been done to make Loran-C a more useful, practical system for general aviation.  Specifically, this work deals with the development of new software and implementation of this software on a microcomputer (MOS 6502) to provide high quality navigation information directly to the pilot.

This software development provides Area/Route Navigation (RNAV) information from Time Differences (TDs) in raw form using an elliptical Earth model and a spherical model [1].  It is prepared for the microcomputer-based Loran-C receiver developed at the Ohio University Avionics Engineering Center.  To compute navigation information, a (MOS 6502) microcomputer and a mathematical chip (AM 9511A) were combined with the Ohio University Loran-C receiver.  Final data in this report reveals that this software does indeed provide accurate information with reasonable execution times.

## II. COMPUTATION FOR AREA NAVIGATION

### A. Range and Bearing Angle

The computation of range and bearing angle between two points on Earth is not simple, because the shape of the Earth is an irregular ellipsoid. It is not necessary to do exact measurements, but there is certain accuracy which is required for area navigation (Advisory Circular 90-45A [2]). On the other hand, the memory capacity and execution time of the microcomputer are considerations for a microprocessor-based Loran-C receiver.

The elliptical Earth model designed by the Aeronautical Chart and Information Center [3] was chosen for this computation. This model gives sufficient accuracy and is feasible for the area navigation application. The equations for range and bearings are the following:

$$\text{Range} = a\,\theta - \frac{a\,f}{4}\Bigg[ (\sin\beta + \sin\beta_1)^2 \; \frac{1 - \cos\theta}{\sin\theta} \; \frac{\theta - \sin\theta}{\sin\theta} \; +$$

$$\left(\frac{\sin\beta - \sin\beta_1}{\sin\beta}\right)^2 (1 + \cos\theta)\,(\theta + \sin\theta) \Bigg]$$

$$\text{Bearing} = \tan^{-1} \frac{\cos\beta_1\,\sin(\lambda - \lambda_1)}{\cos\beta\,\sin\beta_1 - \sin\beta\,\cos\beta_1\,\cos(\lambda - \lambda_1)}$$

where   a = major (equatorial) radius
f = flattening of reference ellipsoid
$\phi$ = geodetic latitude of the receiver
$\phi_1$ = geodetic latitude of the waypoint

$\tan\beta = (1 - f)\tan\phi$
$\tan\beta_1 = (1 - f)\tan\phi_1$

$\theta$ = angle from receiver to waypoint
$\lambda$ = geodetic longitude of the receiver
$\lambda_1$ = geodetic longitude of the waypoint

### B. Cross Track Error

Cross track error (CTE) indicates the position error measured on the perpendicular from the desired track to the actual position of the aircraft. Cross track error bearing (CTEB) indicates the angle difference between the desired track and actual track. Since the error of the

spherical model is small for a short distance, the spherical trigonometry is adequate for the CTE calculation which provides small distance indications (less than 10 nm).

## C. Ground Speed and Estimated Time of Arrival

As an application for Loran-C area navigation, the computation cycle is about 1.3 seconds and the range difference is less than 0.1 nm, so that a small range error causes a large ground speed (GS) error. To solve this problem, averaging is applied after sixteen GS are calculated. But averaging is not a complete solution, because each measuring point has at least 0.2 nm floating error which causes at least 45 nm error after the averaging with sixteen references. More references produce more accurate averaging; however, this consumes more of the limited memory space.

The recursive filter loop is added after the averaging. This filter is a valuable aid in data smoothing and prediction, and is easily implemented on a microprocessor system [4]. In this case, only the first-order gain is considered because of the memory capacity limit:

    Initial condition is:
        GS = 0

    Inside the loop:
        GS = GSP + G1(GSO - GSP)

    For the next calculation:
        GSP = GS

    Where  GSP is ground speed predicted
           GSO is ground speed observed by Loran-C receiver
           G1 is first-order gain.

Estimated time of arrival (ETA) can be output after the calculations of range and ground speed are available.

III.    THE MICROCOMPUTER SYSTEM APPLICATION

A.  Hardware

The microprocessor is the heart of the hardware system. The MOS Technology 6502 was chosen for the Loran-C receiver, developed at Ohio University, because of the low price and speed. Most of the microprocessor work done at Ohio University was done using a Super-Jolt microcomputer [5].

The TD-to-position and area navigation calculations involve multiprecision addition, subtraction, multiplication, division, and trigonometric functions. Additionally, it is necessary to use a floating-point format since the numerical range is approximately $10^{-7}$ to $10^6$ for the calculations. It is desirable to use an external device to support the microprocessor for these calculations.

The AM 9511A by Advanced MicroDevices, a peripheral mathematics processor, is used to do the necessary floating-point calculations. In order to interface the AM 9511A to the Jolt microcomputer system, a M6820 peripheral interface adapter (PIA) is used as the additional hardware interface.

A CRT display is attached to the Ohio University Loran-C receiver. In order to display navigation information on the CRT screen, a VDM-1 videographic board by Micro Computer Products, which utilizes a MC6847 video display chip, is used.

B.  Interfacing Software

A set of subroutines, developed by Fischer ([1], pp. 76-80), initializes the hardware interface and the 9511, writes a single floating-point (32-bit) number, read a floating-point (32-bit) number, send an eight-bit word to the 9511 representing a command to be executed, and read the 9511 eight-bit status register.

C.  Navigation Programs

There are two navigational programs for the Loran-C receiver. Main program "LORPROM4" does Loran-C phased locked-loop operation to provide two TDs [6]. After two TDs are calculated, ten GRIs later, the main program jumps to the subprogram "FRNAVN2." There are two parts in this subprogram. Part one, "COORD," provides coordinates of the position using two TDs as input data, and the part two, "RNAV", provides area navigation information after the position is computed.

The main program and subprogram form one loop which takes about twelve to thirteen GRIs to execute. Figure 1 shows the scheme of the navigation software and the address map for the two programs.

## D. RNAV Program

The "RNAV" program is the main subject of this report. Figure 2 shows the flow chart of the whole program. There are four parts in this program.

The first part of the RNAV program takes care of finding selected from/to waypoints from the user's waypoint table, displaying from/to waypoints and converting the degree, minute, second format (BCD) to the floating-point format in radian units. The coordinates of waypoints and desired waypoint numbers are input into the waypoint table from the keyboard by the user.

The second part of the RNAV program calculates range and bearing angle. For the first loop, which includes all programs (LORPROM4, COORD, and RNAV), the user chooses desired waypoints which calculate range and bearing angle of the desired course. From the second loop, it starts calculating range and bearing angle between the position of the aircraft and a TO waypoint.

After range and bearing angle are calculated, "RNAV's" third part calculates CTEB and CTE. This is very convenient for a user to display whether the off-course is to the left or right. Letter "L" or "R" is added to the front of CTEB display to correct the course. Also, a CDI display is added on the CRT screen. The CDI display has a range of ±2 nm and a resolution of 0.1 nm.

RNAV's fourth part takes care of the ground speed calculation and estimated time of arrival at the waypoint. Since averaging is applied for the ground speed calculation, the first sixteen loops collect references of range, CTEB, and GRI loop number. After sixteen loops, this part calculates the average ground speed using sets of sixteen references. If one loop takes thirteen GRI (for example: GRI = 99600μs), the average period becomes about 1.3 seconds. After the averaging, the average ground speed goes through recursive filter loops, as was mentioned before. The first-order gain of 0.035 is used for the Ohio University Loran-C receiver because it provides the fastest response without noisy data. Although this response is still slow for an accelerative flight, it is reasonable for a constant ground speed representative of cruise flight.

All navigation information is displayed on a CRT screen. Figure 3 shows a Loran-C receiver display. To display information on the screen, all data except CDI must be converted from floating-point format to BCD.

# IV.    TEST RESULTS

Accuracy tests were accomplished by picking random locations in the Loran-C coverage region. According to the simulation of the RNAV program, the range/bearing calculation indicates high accuracy (see Table 1). Although TD-to-position coordinate conversion error is considered, the accuracy is on the order of 0.1 to 0.3 nm. Moreover, the effects of the deviation of the TDs in the receiver should be considered; however, this effect is a function of how the Loran-C pulse is sampled.

Flight testing was done to prove the capability of the Ohio University Loran-C microcomputer-controlled navigation system. The test showed about ±0.5 nm position accuracy ( [1] , pp. 94-97). Therefore, this system indicates a sufficient accuracy for enroute/terminal navigation and for certain landing approaches. However, since the accuracy is mainly dependent on the deviation of the TD's, more studies are needed for this receiver design. Additional flight tests are scheduled to check the ground speed responsiveness with a CDI display for enroute landing approach.

# V.    ACKNOWLEDGEMENTS

## VI. REFERENCES

[1] Fischer, Joseph P., "A Microcomputer-Based Position Updating System for General Aviation Utilizing Loran-C," M.S. thesis, Ohio University, Athens, Ohio, March 1982.

[2] "FAA Advisory Circular 90-45A," Department of Transportation, Federal Aviation Administration, Washington, D.C., 20590, February 1975.

[3] "Geodetic Distance and Azimuth Computations for Lines Over 500 Miles," Aeronautical Chart and Information Center, Technical Report No. 80, St. Louis, Mo., December 1959.

[4] Norris, D. O., and L. E. Snyder, "Analysis of the Automatic Traffic Advisory Resolution Service (ATARS) Tracking and Turn Detection Function," OU/AEC/EER 47-6, Avionics Engineering Center, Department of Electrical Engineering, Ohio University, Athens, Ohio, August 1981.

[5] "JOLT Demon Software Manual," Microcomputer Associates Inc., Santa Clara, California, 1975.

[6] Lilley, R. W., and D. L. McCall, "A Loran-C Prototype Navigation Receiver for General Aviation," OU/NASA Technical Memorandum 80, Avionics Engineering Center, Department of Electrical Engineering, Ohio University, Athens, Ohio, August 1981.

| Range/Bearing Mean Error without Coordinate Conversion Error | | |
|---|---|---|
| | Range | Bearing |
| 0 < Range < 100 nm | 0.001 nm | 0.03° |
| 100 < Range < 200 nm | 0.006 nm | 0.05° |
| 200 < Range < 300 nm | 0.015 nm | 0.04° |

| Range/Bearing Mean Error with Coordinate Conversion Errors | | |
|---|---|---|
| | Range | Bearing |
| 0 < Range < 100 nm | 0.072 nm | 0.07° |
| 100 < Range < 200 nm | 0.121 nm | 0.06° |
| 200 < Range < 300 nm | 0.304 nm | 0.05° |

Table 1.- Range/bearing calculation accuracy.
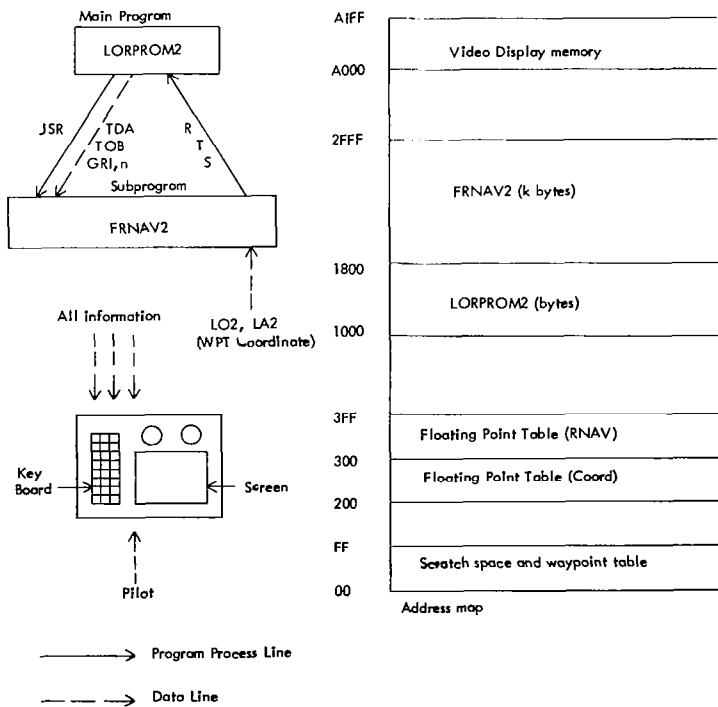


Figure 1.- Loran-C receiver software.
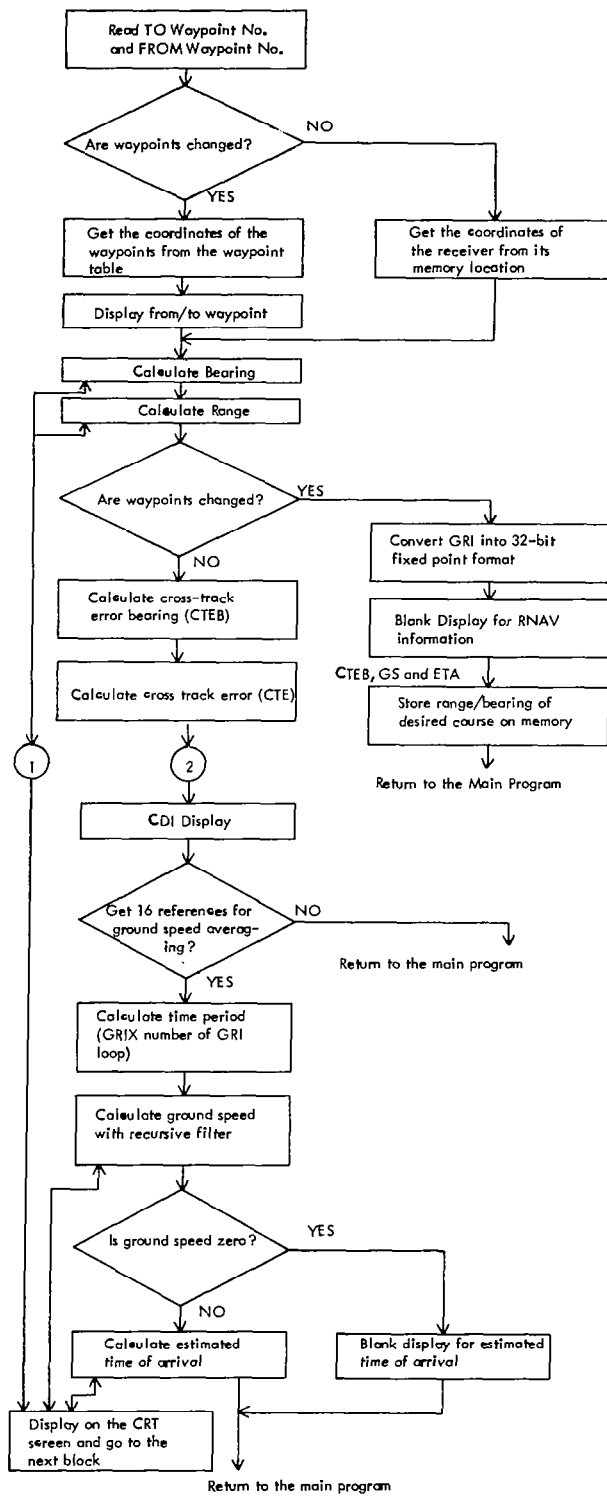
Figure 2.- Flow chart of RNAV program.

```
      0 1 2 3 4 5 6 7 8 9 A B C D E F   0 1 2 3 4 5 6 7 8 9 A B C D E F
$A000 G R I     9 9 6 0 0         F R O M   W P # 1   0 3 8   5 2     0 0
  20  E V E N T #   0 0                             0 8 1   5 2     0 5
  40  L L   1                   T O     W P # 2   0 3 9   4 2     2 0
  60                                               0 8 2   1 1     4 0
  80          M
  A0  3 9   3 3   2 E   0 D           R A N G       4 1 . 4   N M
  C0  T     T     T                   B R N G   3 4 2 . 8   D E G
  E0
$A100 T D A     0 4 2 4 2 8 . 9       C T E   L 0 0 . 2   N M
  20  T D B     0 5 6 8 0 5 . 0       C T E B   0 0 0 . 3   D E G
  40
  60  L A T     3 9   0 2   4 5       G S       1 0 5   N M / H
  80  L O N G   8 1   5 5   5 0       E T A     0 0 : 2 3 : 3 9
  A0
  C0
  E0  C D I     2       1       0       1       2       N M
```

Figure 3.- Loran-C receiver CRT display.

# LORAN-C RF PROCESSING

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Athens, Ohio 45701
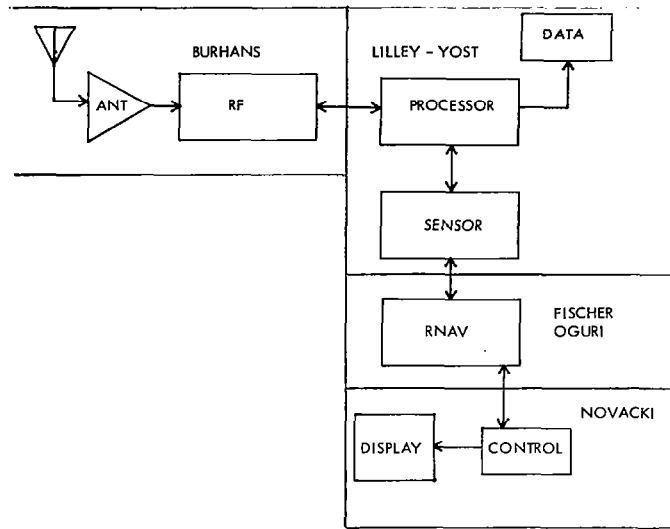
**LORAN-C RECEIVER EFFORT**
**1981-1982**
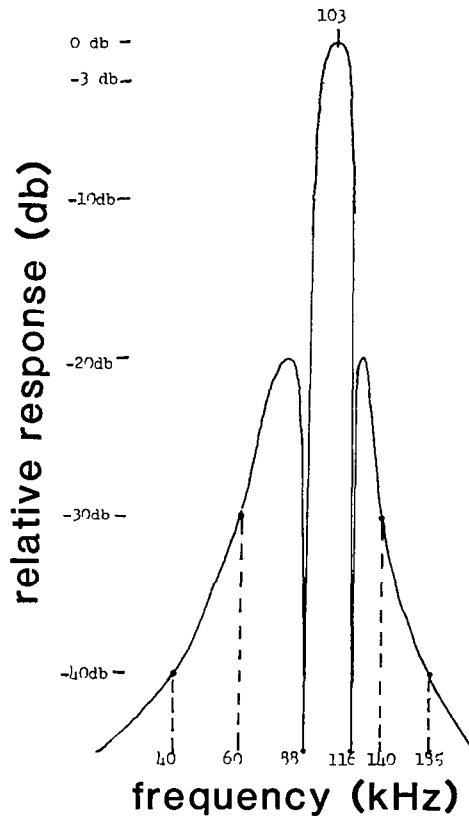


**Combined Response**
**Active Antenna & Loran-C Input Network**
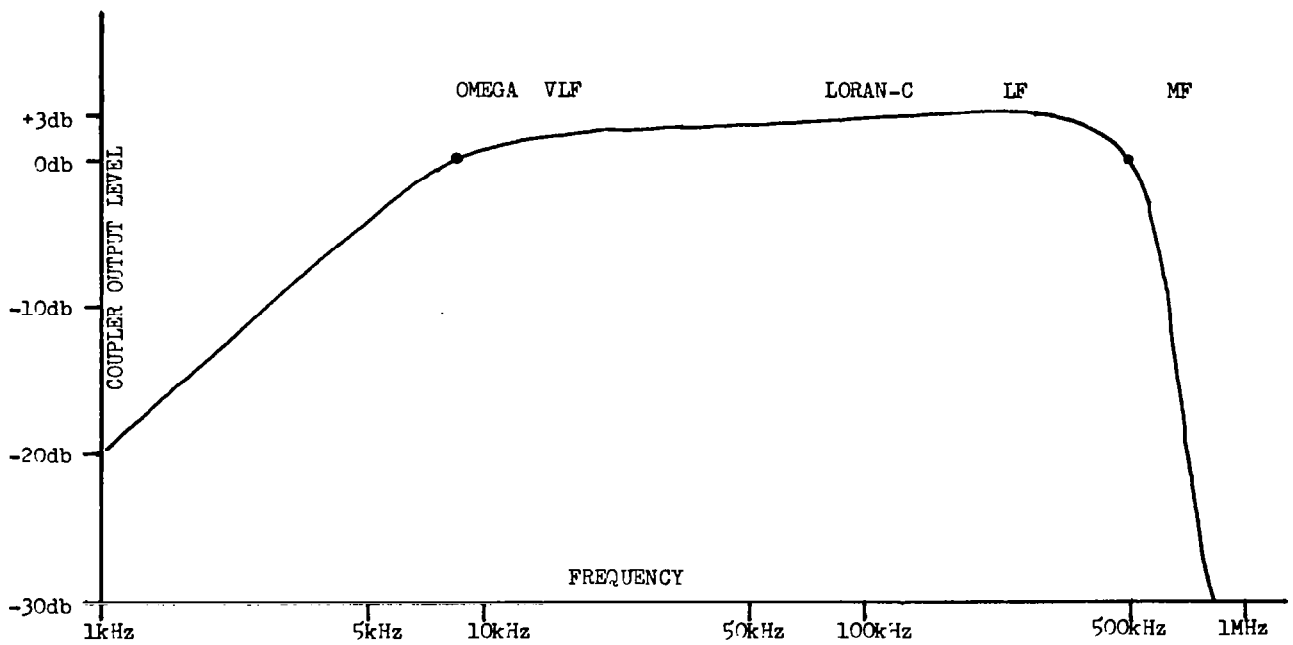
**VLF-LF Active Antenna Response**

1.9"

1.2"

E    C

P    H
     L
     V

gnd. +8VDC

NE-2

T           1mf

$L_1$

antenna    Ct
in

1meg        .01mf

$L_2$        J-310
            GSD

coax

L        1mf    1mf
              22 ohm

LO-Z out

L        500    HI-Z out

C(.02mf)
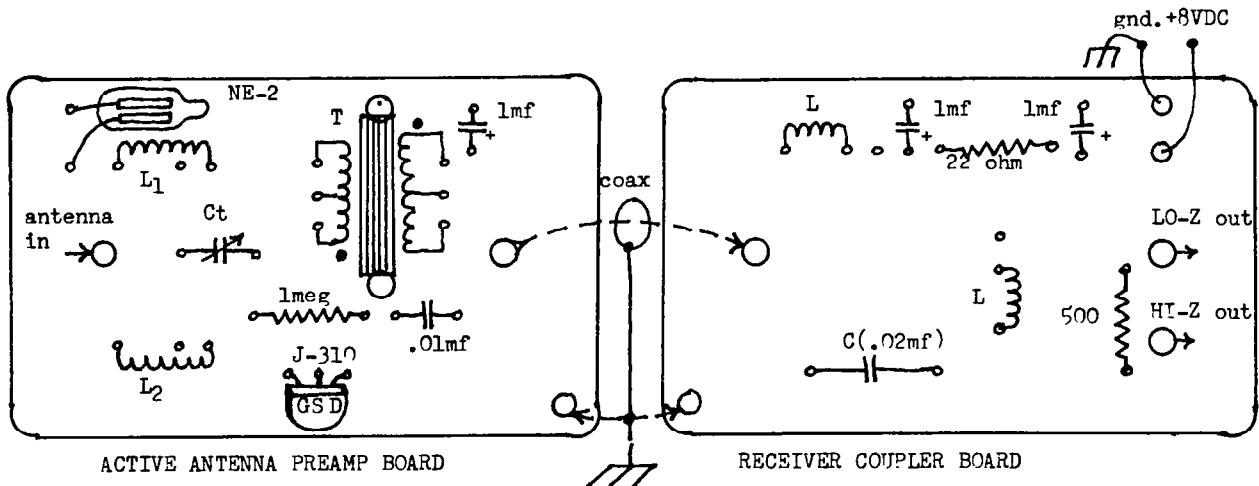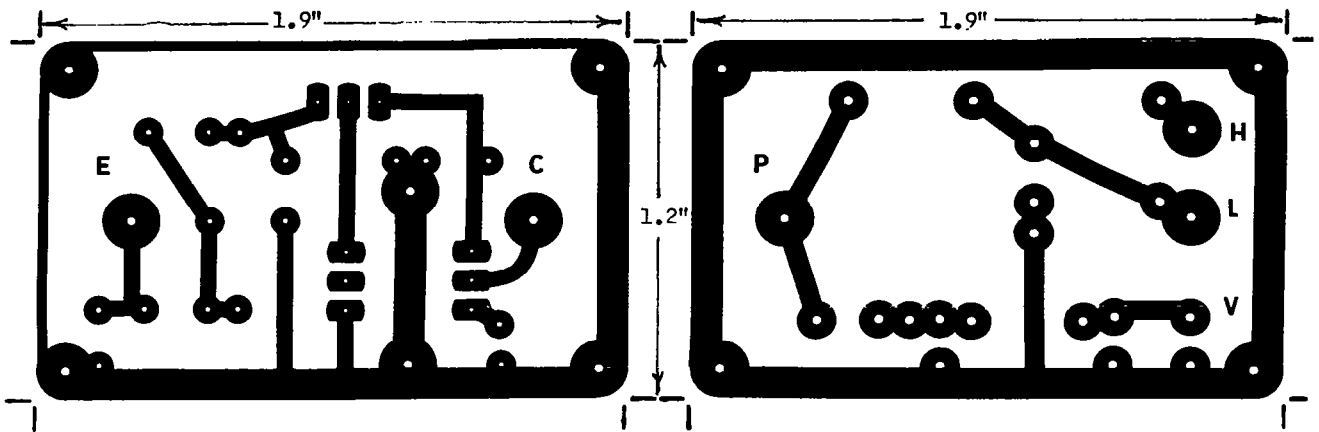
ACTIVE ANTENNA PREAMP BOARD          RECEIVER COUPLER BOARD

ant.    150kHz                        80kHz
        lowpass filter J-310          highpass filter
        $L_1$      $L_2$     D
                         T        .01
                    G   S              coax         .02
        $C_t$                                                      50 ohm out
                  1meg                                             TO RECEIVER
        NE-2                          .1          100μH   100μH    500
                                                                   500 ohm out

        $L_1$,$L_2$   33 to 68 mH RF choke                        +8VDC
        $C_t$    9-40pf trimmer cap.        1    22  1            gnd.
        T       Mouser 42TL- series transformer
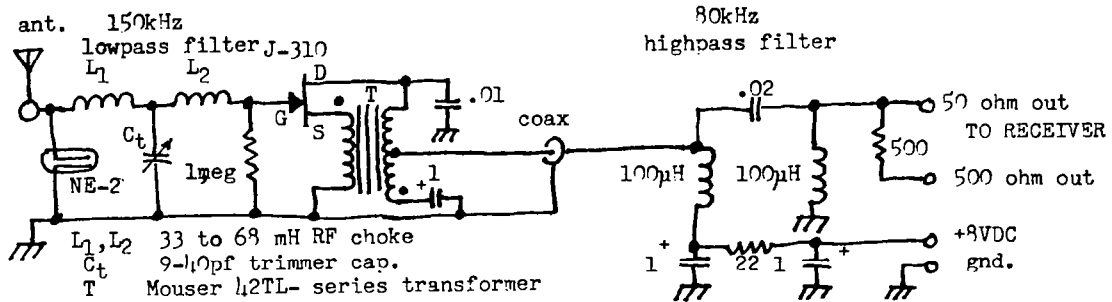
# Active Antenna Boards
# Configured for Loran-C

# Mini Loran-C RF Circuit - 1982
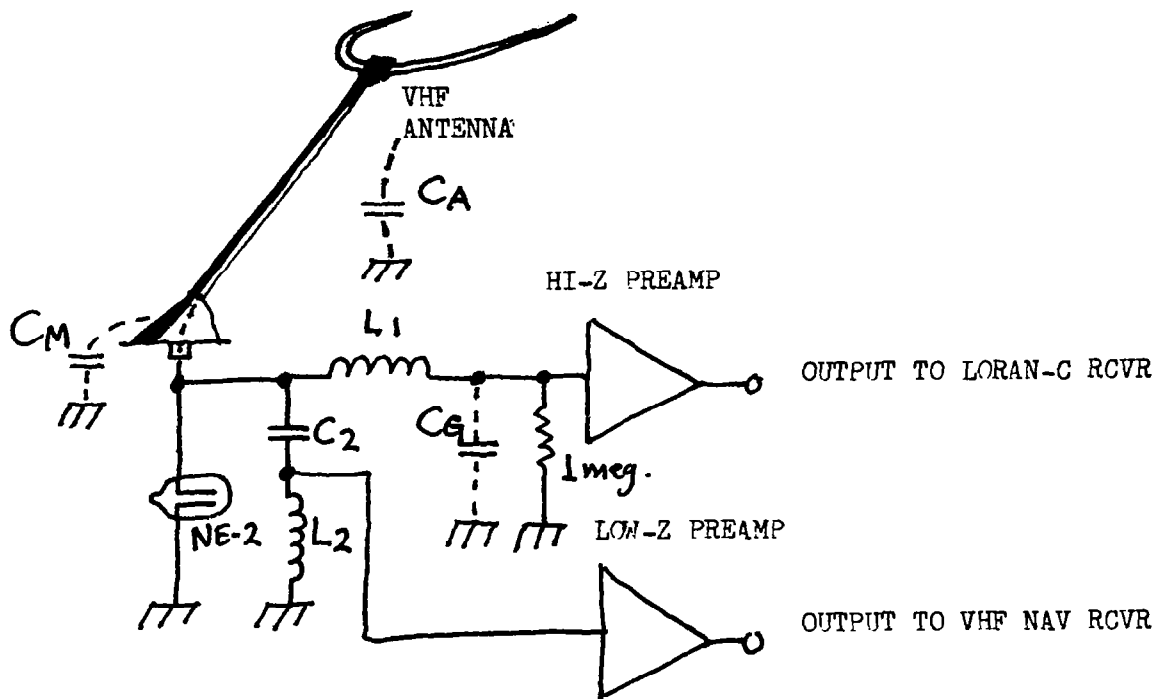
FOR LORAN-C    $X_{L_1} = X_{C_G}$,    $L_1 \approx 82$ mH @ 120kHz

FOR VHF NAV    $X_{L_2} = X_{C_2} = 50$ ohms @ 110 MHz

                    $C_2 = 28$ pf,    $L_2 = 0.7$ μH

PHYSICAL HEIGHT    Approx. 1/4 wave at 110 MHz,   about 60cm (0.6m)

EFFECTIVE HEIGHT    At Loran-C

$$= \frac{C_A}{C_A + C_M + C_2} \times 60\text{cm} \approx \text{about } 10\,\text{cm}$$

# Possible Method of Operating VHF-Nav Antenna for Loran-C
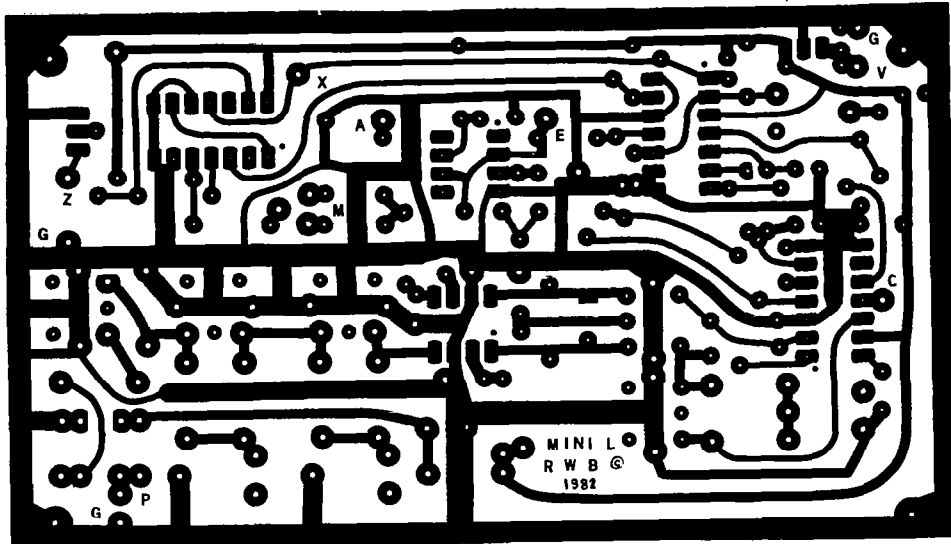
**Mini RF Circuit Board Layout**
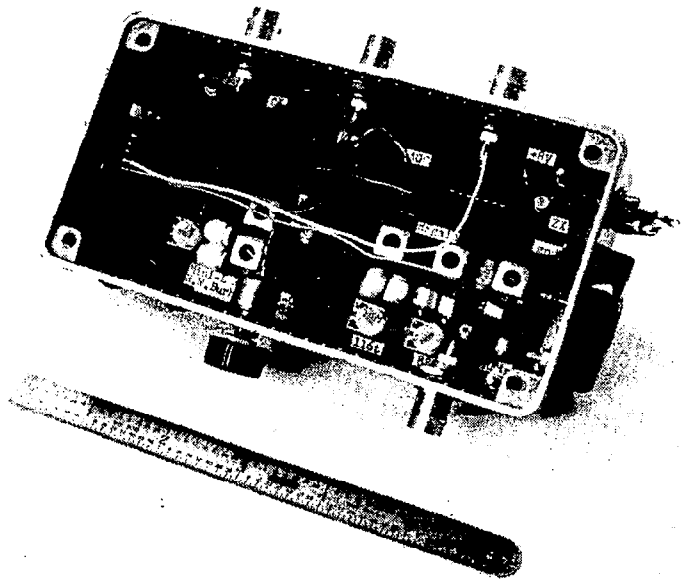


Mini-L-82 RF front end

# LORAN-C RECEIVER REPACKAGING

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# LORAN-C HARDWARE CONSOLIDATION

- IMPLEMENTATION OF VDM-1

- ADDITION OF 8K MEMORY
    - i) 6116 RAM / 2716 ROM

- SERIAL COMM INTERFACE
    - i) 6850 ACIA

## MEMORY MAP

| | |
|---|---|
| | |
| **A1FF** | ALPHANUMERIC/GRAPHICS DATA MEMORY |
| **A000** | VDM-1 CONTROL REGISTERS |
| | |
| **2FFF** | LORAN-C RECEIVER PROGRAM DEVELOPMENT |
| | 8K 6116 RAM AND/OR 2716 ROM |
| **1000** | |
| | |
| **0C01** | 6850 TRANSMIT/RECEIVE DATA REGISTERS |
| **0C00** | 6850 CONTROL/STATUS REGISTERS |

## ADVANTAGES

## VDM-1

* ALL HAV DATA ON A SINGLE PAGE
* GRAPHICS/CDI CAPABILITY
* ? ? ? ?

## 8K MEMORY EXPANSION

* EASY RAM TO ROM PROGRAM CONVERSION

## SERIAL INTERFACE

* BYTE BUCKET
* USER KEYBOARD
* OTHER SERIAL PERIPHERALS

# MULTIPLE BAUD RATE GENERATOR
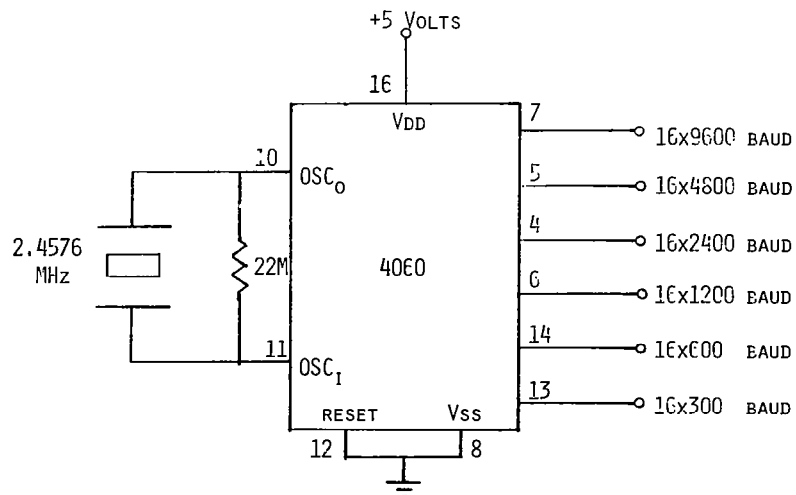
# NEXT TIME.....

## CURRENT FILTERING

* AVERAGE OF 10 TDs EVERY .996 SECONDS
* FIRST ORDER FILTERING

## PROPOSED FILTER

* ALPHA-BETA TRACKING FILTER (GPS ALGORITHM)
   I)  EASILY ADJUSTABLE REACTION TIME
   II) 8 MULTIPLIES AND 4 ADDITIONS PER FIX

# NEW VIDEO DISPLAY FOR THE LORAN-C RECEIVER

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# LORAN–C NEW CRT DISPLAY WITH VIDEO GRAPHIC BOARD (VDM1 manufactured by Micro Computer Associate)

- CDI DISPLAY

   Indicates FTE plus the receiver error

   0.1 resolution

   $\pm$2 nm range

   CDI $\pm$ 2 nm range (enroute)

- FROM/TO WAYPOINT DISPLAY

   Indicates a desired course

```
            ┌─────────────────┐
            │ Convert CTE into│
            │   4 digits BCD  │
            │   format with   │
            │  one tenth nm   │
            └─────────────────┘
                     │
            ┌─────────────────┐
            │   CTE display   │
            └─────────────────┘
                     │
                   ╱   ╲
         "L"     ╱ Check ╲     "R"
       ┌───────╱ the sign ╲───────┐
       │       ╲ of CTE,  ╱       │
       │        ╲"L"or"R"╱        │
       │          ╲   ╱           │
       ▼                          ▼
┌──────────────┐          ┌──────────────┐
│ CDI = -0.1   │          │  CDI = 0.1   │
│ Set a position│         │ Set a position│
│  register    │          │   register   │
└──────────────┘          └──────────────┘
       │                          │
      (A)                        (B)
```

LORAN-C RECEIVER CRT DISPLAY

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $A000 | G | R | I | | 9 | 9 | 6 | 0 | 0 | | | | | F | R | O | M | | W | P | # | 1 | | 0 | 3 | 8 | | 5 | 2 | | 0 | 0 |
| 20 | E | V | E | N | T | # | | 0 | 0 | | | | | | | | | | | | | | | 0 | 8 | 1 | | 5 | 2 | | 0 | 5 |
| 40 | L | L | | 1 | | | | | | | | | | T | O | | W | P | # | 2 | | 0 | 3 | 9 | | 4 | 2 | | 2 | 0 | | |
| 60 | | | | | | | | | | | | | | | | | | | | | | | 0 | 8 | 2 | | 1 | 1 | | 4 | 0 | |
| 80 | | | | | M | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| A0 | 3 | 9 | | 3 | 3 | | 2 | E | | 0 | D | | | | | | R | A | N | G | | | 4 | 1 | . | 4 | | N | M | | | |
| C0 | T | | T | | T | | | | | | | | | | | | B | R | N | G | | 3 | 4 | 2 | . | 8 | | D | E | G | | |
| E0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| $A100 | T | D | A | | 0 | 4 | 2 | 4 | 2 | 8 | . | 9 | | | | | C | T | E | | L | 0 | 0 | 0 | . | 2 | | N | M | | | |
| 20 | T | D | B | | 0 | 5 | 6 | 8 | 0 | 5 | . | 0 | | | | | C | T | E | B | | 0 | 0 | 0 | . | 3 | | D | E | G | | |
| 40 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 60 | L | A | T | | 3 | 9 | | 0 | 2 | | 4 | 5 | | | | | G | S | | | 1 | 0 | 5 | | N | M | / | H | | | | |
| 80 | L | O | N | G | | 8 | 1 | | 5 | 5 | | 5 | 0 | | | | E | T | A | | 0 | 0 | : | 2 | 3 | : | 3 | 9 | | | | |
| A0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| C0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| E0 | C | D | I | | 2 | | | | 1 | | | | | | | | O | | | 1 | | | 2 | | | | N | M | | | | |

# NEW FRONT END INTERFACE AND AGC MODIFICATIONS

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## OVERALL RECEIVER BLOCK DIAGRAM

```
                           ┌──────────┐
                           │ Display  │
Antenna                    │ Terminal │
   ▽                       │Data Entry│
                           └────┬─────┘
                                ↓
┌────────┐   ┌────────┐   ┌──────────┐   ┌──────────┐   ┌──────────┐
│Preamp  │──▶│ RF     │──▶│ Sensor   │──▶│ RS-232   │──▶│ Display  │
│        │   │ Front  │◀──│Processor │   │ Serial   │   │ Terminal │
└────────┘   │ End    │   └──────────┘   │Interface │   ├──────────┤
             └────────┘        │         └──────────┘   │ Byte     │
                               ↓                        │ Bucket   │
                        ┌──────────┐                    └──────────┘
                        │ To       │
                        │ LAT/LONG │   ┌──────────┐   ┌──────┐
                        │Conversion│──▶│ Video    │──▶│ Crt  │
                        │Software- │   │ Display  │   └──────┘
                        │Hardware  │   │ Board    │
                        └──────────┘   └──────────┘
                            │  ↑
                        ┌──────────┐
                        │ RNAV     │
                        │ Software │
                        └──────────┘
```

## SENSOR PROCESSOR

```
┌────────────────────────────────────────────────────────────────┐
│              Superjolt  Microprocessor  Control                  │
└────────────────────────────────────────────────────────────────┘
    │         │  ↑          ↑          │            │
    ↓         ↓             │          ↓            ↓
┌────────┐ ┌────────┐ ┌──────────┐ ┌────────┐ ┌──────────┐
│AGC     │ │Search/ │ │Time      │ │Basic   │ │RS-232    │
│Software│ │Track   │ │Difference│ │Video   │ │Serial    │
│Control │ │Software│ │Generation│ │Display │ │Interface │
│and     │ │        │ │Software  │ │Software│ │Software   │
│Hardware│ └────────┘ └──────────┘ └────────┘ └──────────┘
└────────┘     │  ↑        ↑
          ┌──────────┐
          │Tracking  │
          │Loop      │
          │Software  │
          │and       │
          │Hardware  │
          └──────────┘
```

## AGC BLOCK DIAGRAM



Loran Envelope ▷

DEMULTIPLEXER

Sample and Hold Circuits (Six)

MULTIPLEXER

Gain and Offset

AGC to Front End ▷

Software Equals Pulse ▷

Sampling Pulse Generation

A ○
B ○
C ○
Channel Addressing from Software

## LORAN-C SEARCH/TRACK PARAMETERS



LORAN CHAIN
GRI = 99,600μS

LORAN STATION
PULSE SPACING =
1000μS

LORAN ENVELOPE
ZERO CROSSING
PULSE = 10μS

ZERO CROSSING
PULSE AND
SOFTWARE
EQUALS PULSE
(LENGTH = 1μS)
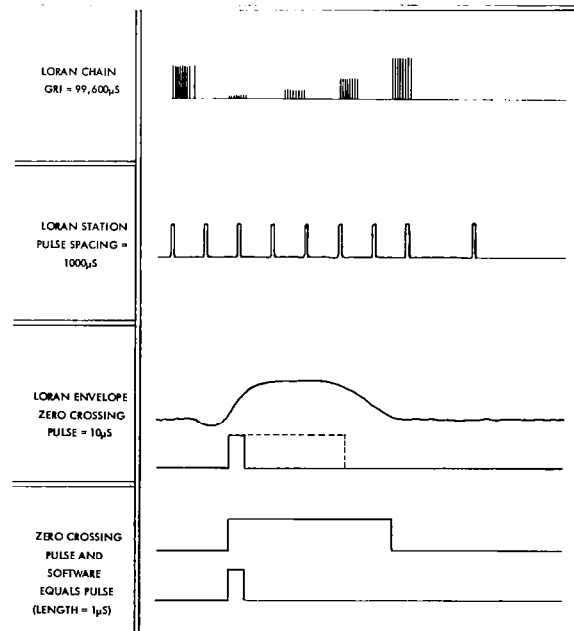
# LORAN-C CONTROL AND DISPLAY

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Athens, Ohio   45701

# Loran-C Control-Display Summary

1. Combination Character/
   Graphics Display

2. Rho-theta Data, Plus Lat-long

3. Multiple Stored,
   Numbered Waypoints

4. Microprocessor Bus Attachment

5. Compact Package

**Receiver Initialization
Using Keyboard**

(Enter from Initialization Routines)

DETECT
KEY
CLOSURE
?
NO
YES

COMMAND
KEY
?
NO

PROCESS
COMMAND

DATA
REQUIRED FOR
COMMAND
?
NO
YES

ACQUIRE AND
FORMAT DATA
FOR USE

(Return to Receiver Operations)
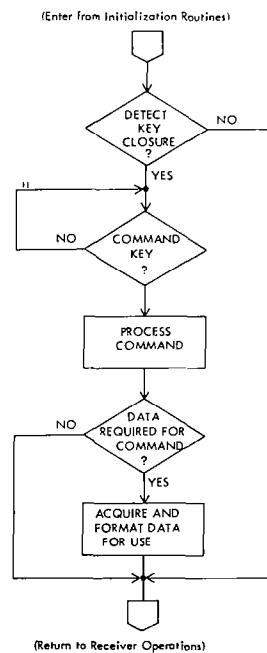
# Loran-C Control Display
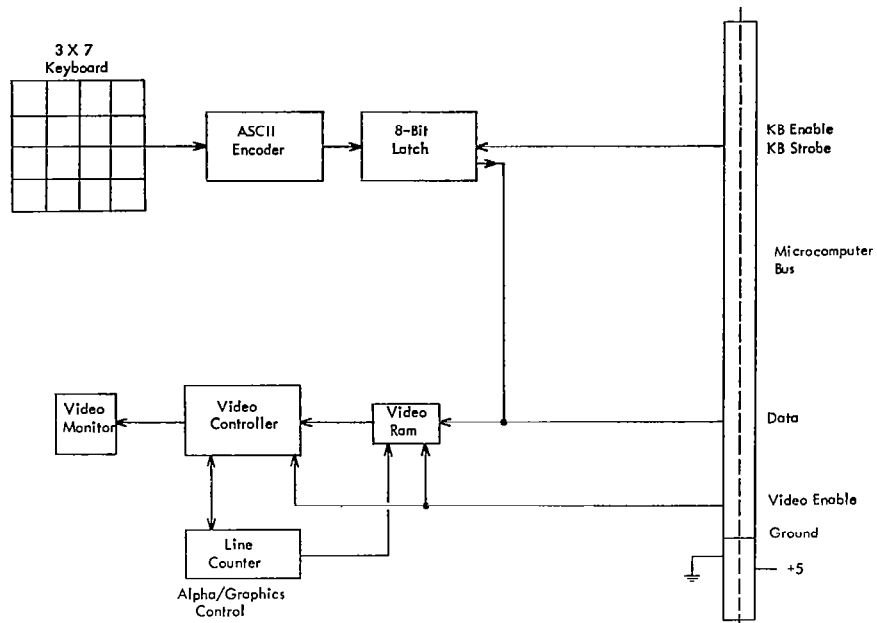


# Keypad
# Evaluation Prototype

ASCII Keyboard Encoder Using AY-5-2376

AY-5-2376
ASCII Encoder

μ 8212
Octal Latch

6530-004
VIA

| Y8 | $AS_0$ | | Di0 | Do0 | | PA0 |
| Y7 | | | | | | |
| Y6 | $AS_1$ | | Di1 | Do1 | | PA1 |
| Y5 | $AS_2$ | | Di2 | Do2 | | PA2 |
| Y4 | | | | | | |
| Y3 | $AS_3$ | | Di3 | Do3 | | PA3 |
| Y2 | | | | | | |
| Y1 | $AS_4$ | | Di4 | Do4 | | PA4 |
| Y0 | | | | | | |
| X7 | $AS_5$ | | Di5 | Do5 | | PA5 |
| X6 | | | | | | |
| X5 | $AS_6$ | | Di6 | Do6 | | PA6 |
| X4 | | | | | | |
| X3 | | | Di7 | Do7 | | PA7 |
| X2 | KP | | STR | | | PB2 |
| VDD | VSS | | GND VCC CLR | | | |

0.01μF

U1        U2

+5V    -12V

1N914    100K

+5V

$U_1$, $U_2$  1/2 74LS00

68
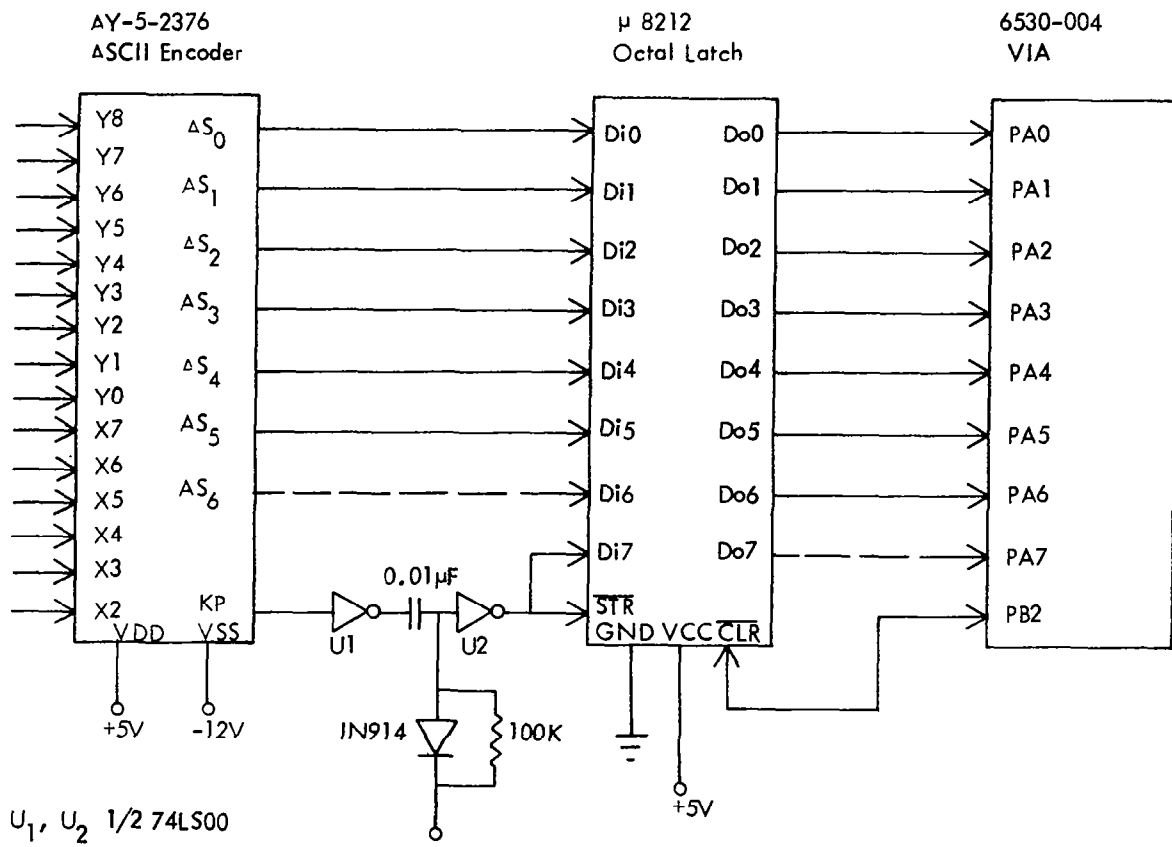
# SUMMARY OF SIMPLE ACTIVE ANTENNAS FOR VLF-LF

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Ohio University
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POWER AMPLIFIERS OR HIGH CURRENT JFET OR VMOS-FET
SEMICONDUCTORS, CLASS A OPERATION

HIGH IMPEDANCE INPUT LOW PASS FILTERS TO REDUCE
INTERMODULATION DISTORTION

BIAS RESISTOR TRIM FOR BEST LINEARITY

FOR E-FIELD:

- USE AS SHORT A SHIP OR BLADE AS POSSIBLE,
  MINIMUM HEIGHT ABOUT 50 CM
- MINIMIZE INPUT CAPACITANCE AT ANTENNA
  MOUNT WITH NO CABLE
- MOUNT ANTENNA IN CLEAR AREA FREE FROM
  NEARBY OBSTRUCTIONS

FOR H-FIELD:

- USE BALANCED WINDING WITH RH-LH CENTER TAP
  OR MOIBUS-TYPE WINDING
- SHIELD LOOP IN TROUGH ENCLOSURE
- MOUNT ANTENNA IN AREA FREE FROM FERRO-
  MAGNETIC MATERIALS (IRON & STEEL)

INPUT STATIC PROTECTION

- NEON BULB FOR E-FIELD WITH JFET
- LIMITER DIODES FOR H-FIELD WITH VMOS-FET

**E-FIELD HIGH-Z UNITY GAIN**

short whip

~ 100mH

J310

bifilar toroid

coax

TO COUPLER

NE99

1meg

22

1

adjust source bias for best linearity

1

**H-FIELD LOW-Z 30db VOLTAGE GAIN**

ferrite rod

LH

RH

VN10KM

0.1

15k

1k    2.2k

200 ohm submin. audio output type, primary only

coax

TO COUPLER

1

adjust gate bias for best signal gain

**RECEIVER INPUT COUPLER**

FROM PREAMP

coax

0.22

TO RECEIVER

1mH

22    250    R

1    1

50 ohm load

adjust series R for best linearity below about 40ma

+V

(+8to+12V, 20-40ma)

## BEST VLF-LORAN-C ACTIVE ANTENNAS (1982)

# Massachusetts
# Institute
# of
# Technology

# INVESTIGATION OF AIR TRANSPORTATION TECHNOLOGY AT MASSACHUSETTS

## INSTITUTE OF TECHNOLOGY, 1982

Robert W. Simpson
Flight Transportation Laboratory
Massachusetts Institute of Technology
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## SUMMARY OF RESEARCH

There have been a variety of research topics sponsored by the Joint University Program during the past year.  Three projects ended at mid-year (i.e., the work on Aircraft Ice Prevention by Microwaves by John Hansman; the P-Pod Display work by James Littlefield; and the Automated Decision Support Systems for Terminal Area ATC by John Pararas).  This research is available in the MIT reports listed in the annotated bibliography that follows.  One new project has been initiated to investigate the use of Loran-C for guidance in flying approaches to landing by general aviation aircraft.  This is described in the conference presentations in this publication.  Also, the research work by John Pararas in developing an ATC simulation for the MVRSF (Manned Vehicle Simulation Research Facility) at NASA Ames Research Center is presented later since it is a direct consequence of his prior work in the Joint University Program.  There is one other area of research which received minor support from the grant.  The thesis of Shinsuke Endoh on a general theory for air traffic collision models is listed in our annotated bibliography.

## LATERAL APPROACH GUIDANCE TO GA RUNWAYS USING LORAN-C

For the past few years, MIT has been flight testing a low cost marine Loran-C receiver in various applications to enroute and approach flying. The success in conducting non-precision approaches has raised the possibility of using Loran-C to provide good lateral guidance to the runway for general aviation aircraft.  This research is aimed at investigating the dynamic performance of a runway lateral guidance system which would use a simplified method of processing time difference data in a local reference grid plane centered on the runway touchdown point, a local Loran-C update at time of approach, and some heading rate augmentation from a fluidic rate gyro.  The issue is the dynamic response of the system to cross track errors.

If successful, Loran-C would provide a very attractive low cost system for enroute navigation and for approach lateral guidance to any runway within good coverage of a Loran-C chain.  Currently, the enroute R-NAV or L-NAV mode uses a latitude-longitude reference system to define waypoints for flying airways or direct cross-country flights.  Multiple waypoints can be identified by their 3-letter aviation code stored in EPROM chips.  It is feasible to have a second approach mode of processing the time differences for surveyed runway touchdown points and the L-NAV approach chart geometrics.  It appears to be possible to supply lateral guidance from beyond the approach fix to the runway. Also, information on distance/time to touchdown and nominal approach altitudes can be provided.  In the approach mode, it is possible to navigate to the final approach fix, and to switch easily to a missed approach fix if a go-around is necessary.

This project has now selected a new Loran-C marine receiver as the basic building block for the system. It is the Micrologic ML-3000 with custom built software for special I/O features which provide a real time stream of time difference data. An aircraft antenna and coupler have also been selected.

Endoh, Shinsuke:  Aircraft Collision Models.  Flight Transportation
Laboratory Report R82-2, Department of Aeronautics and Astronautics,
MIT, May 1982.

In air traffic control, the gas model of classical physics has been
borrowed to describe the expected frequency of mid-air collisions for
uncontrolled aircraft moving randomly in the airspace.  In this study, the
gas model is extended to a comprehensive general conceptualization which can
describe the mid-air collision rate (or conflict rate, or encounter rate)
for uncontrolled air traffic in a wide variety of practical situations such
as overtaking along an airway, intersections of two airway traffic flows,
IFR-VFR encounters for an airway imbedded in a VFR area, radial flow patterns
around an airport, etc.  By prescribing the probability density functions
(pdf) for horizontal position, speed, direction, vertical rate of climb, and
altitude, it becomes possible to study the effects of traffic concentrations
on collision  or encounter rate, and consequently on air traffic controller
workload.  It is proved that a uniform distribution of direction maximizes
collision rate while a uniform distribution of position minimizes collision
rate.  By gathering data on the pdf's of air traffic in a given ATC sector,
it will be possible to provide assessments of general level of risk and
controller workloads as a function of traffic flow rates or density.

Hansman, Robert John, Jr.:  The Interaction of Radio Frequency
Electromagnetic Fields with Atmospheric Water Droplets and
Applications to Aircraft Ice Prevention.  Flight Transportation
Laboratory Report R82-5, Department of Aeronautics and Astronautics,
MIT, June 1982.

In this work the physics of advanced microwave anti-icing systems,
which pre-heat impinging supercooled water droplets prior to impact, is studied
by means of a computer simulation and is found to be feasible.  In order to
create a physically realistic simulation, theoretical and experimental work
was necessary and the results are presented in this work.

The behavior of the absorption cross-section for melting ice particles
is measured by a resonant cavity technique and is found to agree with
theoretical predictions.  Values of the dielectric parameters of supercooled
water are measured by a similar technique at $\lambda = 2.82$ cm down to $-17^{\circ}$C.
The hydrodynamic behavior of accelerated water droplets is studied
photographically in a wind tunnel.  Droplets are found to initially deform as
oblate spheroids and to eventually become unstable and break up in Bessel
function modes for large values of acceleration or droplet size.  This

confirms the theory as to the maximum stable droplet size in the atmosphere. A computer code which predicts droplet trajectories in an arbitrary flow field is written and confirmed experimentally. Finally, the above results are consolidated into a simulation to study the heating by electromagnetic fields of droplets impinging onto an object such as an airfoil. Results indicate that there is sufficient time to heat droplets prior to impact for typical parameter values, and design curves for such a system are presented in the study.

Littlefield, James A.:  A Programmable Pilot Oriented Display System for General Aviation Aircraft.  Flight Transportation Laboratory Report R82-4, Department of Aeronautics and Astronautics, MIT, May 1982.

This report presents a complete description of a digital flight data processing platform designed to support a range of airborne or flight simulator-based experiments requiring the acquisition, processing, and display of information.  The Programmable Pilot Oriented Display (PPOD) is based on IEEE S-100 bus standard equipment and readily available software utilities. The design philosophy and techniques used to achieve project objectives with a minimum of hardware/software customization are discussed.  System resources include three Z80 processors, intelligent IO, complete interprocessor communications firmware, and RS-170 composite video output.  Discussion of both PPOD capabilities and the steps required to employ PPOD in future experimental setups are presented in the context of a mobile test run.

Pararas, John D.:  Decision Support Systems for Automated Terminal Area Air Traffic Control.  Flight Transportation Laboratory Report R82-3, Department of Aeronautics and Astronautics, MIT, June 1982.

This work studies the automation of the terminal area Air Traffic Management and Control (ATM/C) system.  The ATM/C decision-making process is analyzed and broken down into a number of "automation functions".  Each of these functions is described with particular emphasis on its role in the overall system and its interactions with the other ATM/C automation functions. Runway Scheduling and Traffic Flight Plan Generation are identified as the two functions with the greatest potential for providing efficiency improvements over the current terminal area ATC system and are studied in detail.

A very general Mixed Integer Linear Programming (MILP) formulation of the Runway Scheduling problem is developed.  Less general formulations and algorithms which have appeared in the literature are reviewed and evaluated. A heuristic algorithm is developed.  The algorithm is based on the work of Dear and adopts the Maximum Position Shifting methodology proposed by him (ref. 1).  It extends Dear's work in several ways: (1) it is applicable to multiple runway configurations, (2) it is designed to operate in a real-time simulation environment, and (3) it is designed to accept arbitrary constraints imposed by the ATM/C controller.

The methodology for generating flight plans is developed.  Flight plans

are based on a specified route structure. They are four-dimensional and conflict-free. To allow maximum runway scheduling flexibility, a specific route structure is proposed. It is designed to allow easy modification of flight plans to adapt to the dynamically changing schedule.

To allow algorithmic development and testing of this (as well as other) ATM/C automation concepts, a real-time terminal area simulation facility (called TASIM) is designed and implemented. The facility has a number of characteristics which make it a good general-purpose tool for terminal area ATM/C research:

(1) Highly modular design which allows addition, removal and modification of functions with relative ease

(2) Realistic modelling of the aircraft dynamics of motion and the aircraft guidance system (errors introduced by the navigation equipment (onboard and on the ground) and by the surveillance radars are also modelled)

(3) Capability to simulate multiple controller positions

(4) Flexible controller interface which allows easy implementation of alternative displays and alternative protocols for man-machine interaction

The simulation is fully operational in the conventional (manual) ATC mode. In addition, it is currently interfaced with an implementation of the runway scheduling heuristic, and with a special purpose final vectoring display designed to aid the controller in precisely timing the delivery of landing aircraft at the outer marker.

## REFERENCE

1. Dear, Roger D.: The Dynamic Scheduling of Aircraft in the Near Terminal Area. Flight Transportation Report R76-9, Dept. of Aeronautics and Astronautics, Massachusetts Institute of Technology, Cambridge, Mass., Sept. 1976.

# LATERAL RUNWAY APPROACH GUIDANCE USING LORAN-C

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## RESEARCH OBJECTIVES

The objectives of this project are to design and flight test a lateral guidance system for flying approaches to a runway by general aviation aircraft. The issue is whether or not good dynamic response can be obtained by exploiting the repeatable accuracy of Loran-C position data and combining it with heading rate data. We would like to provide the pilot with cross-pointer displays such that he can keep the aircraft within ±75 feet of the runway centerline at approach speeds typical of general aviation aircraft.

## RESEARCH ISSUES -

CAN WE USE LORAN C DATA TO PROVIDE GA AIRCRAFT

WITH GOOD LATERAL GUIDANCE TO ANY RUNWAY? IF SO,

LORAN C RECEIVER CAN PROVIDE GA WITH ENROUTE

NAVIGATION, PLUS LANDING GUIDANCE. DO WE NEED

HEADING RATE DATA FROM RATE GYRO TO OBTAIN GOOD

ESTIMATES OF CROSS TRACK VELOCITIES?

## SYSTEM CONCEPT

Normally, for enroute navigation Loran-C data is converted to a latitude-
longitude reference frame which requires extensive processing and is not suitable
for simple guidance. This shows the estimation of current position and guidance
information, but is more than adequate for enroute flying and for flying non-
precision approaches similar to those which use NDB's or VOR's. If we are to
provide lateral guidance to the runway centerline such that cross-track deviations
and velocities are quickly detected, it is desirable to switch to a local reference
grid plane centered at the touchdown point. This allows us to filter the Loran-C
data easily and with much simpler processing, and also requires very little geometric
data and processing algorithms to be stored in onboard computer memory.

1. THERE CAN BE TWO MODES OF PROCESSING LORAN C

   DATA FROM RECEIVER

   A) ENROUTE - LAT-LONG CONVERSION OF TD'S

      FOR LONG LEGS BETWEEN WAY

      POINTS

   B) APPROACH - LOCAL REFERENCE GRID PLANE

      CENTERED AT TOUCHDOWN PT.

      ON RUNWAY, X-AXIS IN RUNWAY

      DIRECTION

## SYSTEM OPERATIONAL CONCEPT

The Loran-C system is used in its R-NAV mode enroute.  In the vicinity of the airport, the pilot receives altimeter setting and also two Loran-C corrections from nominal surveyed TD's at airport.  These corrections are entered (if necessary), the runway approach is selected, and the system is switched to APPROACH mode.  Altitudes, distances, final approach fix, and missed-approach fixes are stored in memory for this approach.  The approach mode supplies guidance to the final approach fix, to the touchdown point, and if necessary to the missed-approach fix.  Distance and track to each point are available at all times, along with the minimum desired altitude.

2.  UPON REACHING AREA OF AIRPORT, PILOT RECEIVES ALTIMETER SETTING, PLUS $\Delta 1, \Delta 2$ CORRECTIONS FOR CURRENT DEVIATION FROM NOMINAL LORAN C TD'S AT AIRPORT.

3.  APPROACH GEOMETRY AND ALTITUDES STORED IN ROM. PILOT SELECTS APPROACH IDENTIFICATION.

4.  SIMPLE, RAPID STANDARDIZED PROCESSING OF TD'S TO PROVIDE ESTIMATES OF POSITION AND SPEED WITH GOOD DYNAMIC RESPONSE FOR GUIDANCE DISPLAYS.

5.  NO VERTICAL GUIDANCE, BUT DISPLAY OF RANGE TO TOUCHDOWN OR OUTER MARKER, AND DESIRED ALTITUDE ON APPROACH.

## SYSTEM DESIGN PLANS

We have a Digital Marine North Star 6000 receiver which can serve as the ground station. We plan to acquire a Micrologic ML 3000 marine receiver, which will be modified to provide a real-time stream of digital data on time differences. This data will be sent to a guidance processor system designed and built by MIT which will compute positions in a local reference grid and filter or track the aircraft position and position rate. A fluidic rate gyro (based on original NASA LaRC design) has been developed at MIT and will provide heading rate information. The guidance outputs will be sent to an ordinary HSI instrument or to the P-POD display.

1. LORAN C RECEIVER

- DIGITAL MARINE NORTH STAR 6000 (MARINE)

- MICROLOGIC ML-3000 MARINE NAVIGATOR

    - OUTPUT PORT FOR TD'S (TO Z-80)

    - PRICE $2700 (DISCOUNT - $1700)

    - 9x5x11 INCHES

    - WEIGHT 9 LBS.

    - PRE-AMP AND WHIP ANTENNA $483 (305)

    - FULL NAVIGATION OUTPUTS

2. PROCESSOR BOX - MIT

3. DISPLAY - HSI (?)

        - P-POD

The guidance processing can be done in a small 1/4 ATR box, which has various input and output devices on its face. An external plug-in EPROM will be used to establish the runway geometries, processing coefficients, guidance programs, and so forth. This is easy to create and modify external to the box using the P-POD microcomputer-based development system, and is then plugged in for testing. The pilot can select the approach to be flown, and can insert the two Loran-C updates using thumbwheels. He will see range and desired altitude in digital data format.

## 2. Processor Box (1/4 ATR)
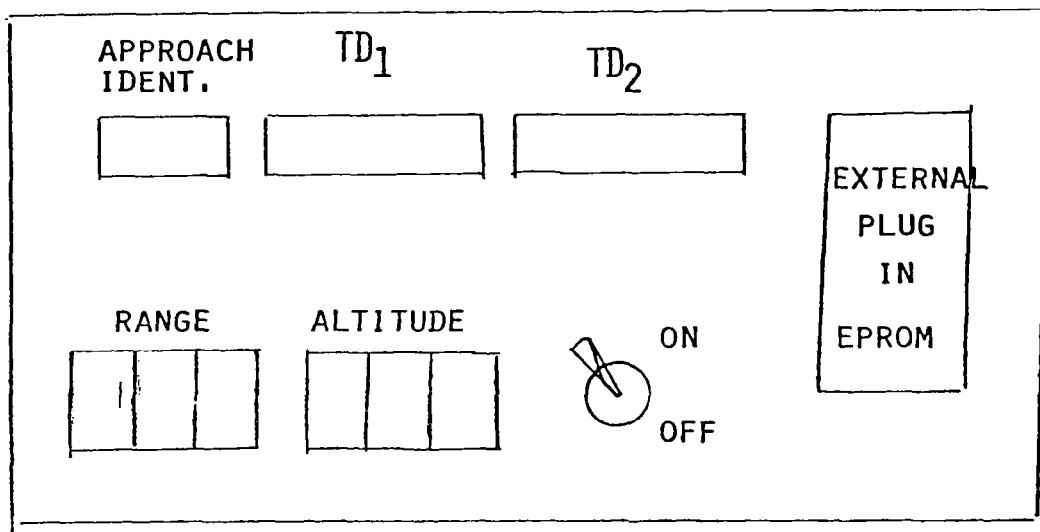


CONTAINS - EPROM (RUNWAY GEOMETRY, COEFFICIENTS)

- Z-80 PROCESSOR

- CLOCK

- I/O CHIPS, A/D CONVERSION

- POWER SUPPLY

- MIT FLUIDIC RATE GYRO (IMPROVED SENSOR)

If the lateral displacement and rate are Y and $\dot{Y}$, respectively, they will be converted from digital estimates to analog inputs that drive an HSI-type display. A possible format is shown, and an alternative is to incorporate the P-POD electronic display, which would provide a more flexible device in constructing various display formats.

# PILOT DISPLAY SYSTEM

HSI



FLAG-(SNR)

| RANGE | | ALTITUDE |
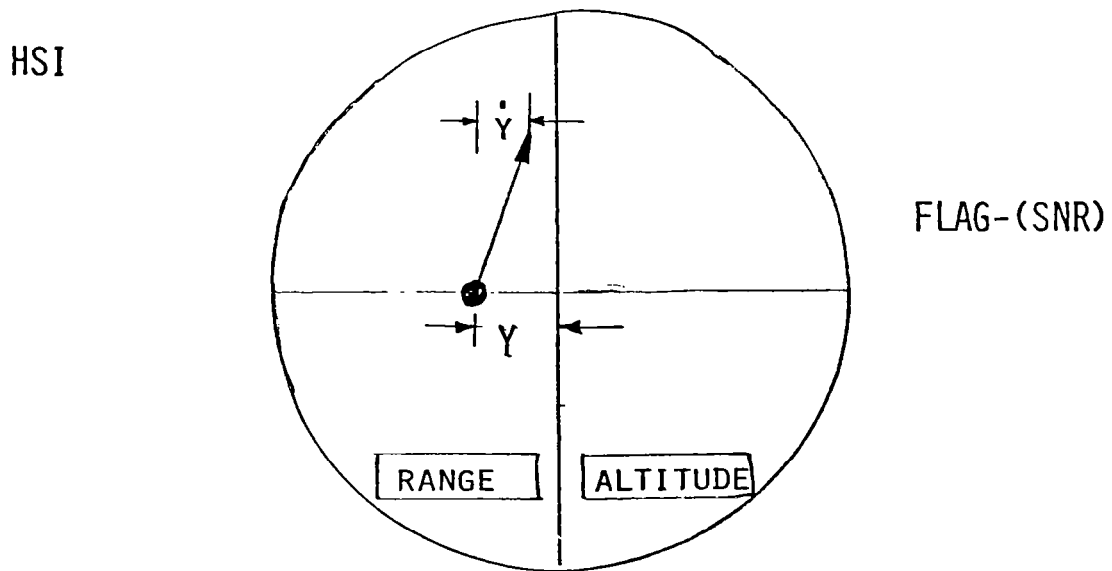
## ALTERNATIVES - P-POD DISPLAY

# DEVELOPMENT OF REAL-TIME ATC SIMULATION FACILITY

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# INTRODUCTION

The Flight Transportation Laboratory has developed a real-time interactive Air Traffic Control simulation facility designed to provide a versatile and easy-to-use tool for research and experimentation involving Air Traffic Control. The facility uses a VAX-11/750 as the central computer. The SANDERS GRAPHICS-7 display system is used to simulate air traffic control displays. Pseudo-pilot displays are provided on Texas Instruments TI940 video terminals. Finally, a custom-designed audio system driven by a Z-80 and interfaced with the VAX provides voice communication between the air traffic controllers and the pseudo-pilots. The audio system provides computer-controlled voice disguising and thus allows each aircraft to have its own audio characteristics and provides an added realism to the experiment.

The facility can accommodate multiple controller stations and pseudo-pilot stations. Each station is manned by a single operator who has a large repertoire of commands with which to control his/her display and the simulated aircraft under his/her jurisdiction. An additional console and a distinct set of commands allow full controllability of the simulation environment by the experimenter in real time.

The ATC facility has the following unique characteristics:

1. Software modularity. In contrast to training simulators, an experiment-oriented simulator can expect frequent software changes and extensions to support new experiment requirements. This is particularly important in the case of ATC research where new software itself is the subject of research (e.g., tracking algorithms, collision avoidance systems, ATC automation algorithms, evaluation of alternative display formats, etc.) The ATC simulation is designed to reduce the cost of adapting it to a particular experiment and interfacing new software by a multiprocessing approach to software modularity.

2. Controllability and repeatability. The facility provides for controllability and repeatability of each experiment through a mechanism called "scripting." This mechanism allows the experimenter, prior to running the experiment, to generate a set of actions and for each action the set of conditions that have to be met for the action to take place. Time logging of simulation events allows the experimenter to determine what took place and in what order during the experiment.

3. Manpower requirements. The facility is designed to minimize the number of operators required for an experiment as well as the amount of training required. The scripting mechanism can be used to automatically activate operator commands, thus minimizing the amount of intervention required. It can also be used to cue operators on actions that they have to take (e.g., verbalizing an ATC clearance or acknowledgement) so that controllers and pseudo-pilots will not require extensive familiarity with ATC before they can be successfully employed in an experiment. In addition, the

pseudo-aircraft will automatically follow a flight plan (if one is present), thus allowing one pseudo-pilot to control up to 12 aircraft, especially in an enroute environment.

PURPOSE:          Research on pilot workload, advanced

                  cockpit instrumentation

REQUIREMENTS:     Full mission simulation (up to 8 hours)

                  in a realistic ATC environment

COMPONENTS:       ATC Subsystem

                  Conventional Cab (B727)

                  Advanced Cab

                  Audio Subsystem

Figure 1.- The MVSRF (Manned Vehicle Systems Research Facility).

# HISTORICAL NOTE

The first version of the simulation (funded by NASA Langley Research Center) was designed and built by Val Heinz in 1976 (ref. 1). It was designed to operate in fast time and it primarily modeled the aircraft dynamics, the navigation and surveillance systems, and the readings of the onboard instrumentation. This software is now the core of POSGEN, one of the processes comprising the simulation facility (see the section on software configuration).

The Val Heinz effort was part of a larger program in air traffic control research at the Flight Transportation Laboratory. Fast time simulation, however, proved to be an insufficient tool for detailed ATC studies. It failed to model the man/machine interface, which in air traffic control is one of the key factors affecting the operation of the system. As a result, the author designed and developed TASIM, a real-time terminal area simulation, by embedding the Val Heinz software into a real-time ATC environment. This (second) version of the simulation was designed to be controlled by a single person (thus the air traffic controller also acted as a pseudo-pilot) and was primarily targeted for terminal area operations. This effort started in 1979 and was complete in 1981. It was funded jointly by the NASA Joint University Program and the MATCALS program of the U.S. Marines.

The third (current) version of the ATC simulation facility was developed for the Man-Vehicle Systems Research Facility at NASA Ames Research Center. The major improvements from the prvious version are:

1. The extension of the ATC environment to include enroute as well as tower and ground ATC sectors

2. The capability to interface with cockpit simulators

3. The implementation of pseudo-pilot stations and thus the divorcing of the pilot task from the traffic control task

4. The interfacing with the audio subsystem, thus allowing realistic simulation of voice communications between the pilots and the controllers

5. The development of a script mechanism to control the simulation environment

PURPOSE:     Provide a realistic ATC environment

             in which cabs will fly their

             experiments


REQUIREMENTS:      -- Realistically simulate pseudo-
                      aircraft movements within the
                      airspace

                   -- Drive multiple controller displays

                   -- Drive multiple "pseudo-pilot"
                      displays

                   -- Manage the allocation and
                      "connectivity" of audio channels

                   -- Provide cabs with ATC data needed
                      to drive onboard instrumentation
                      (CDTI's, out-the-window displays,
                      etc).

Figure 2.- The ATC subsystem - MVSRF.

# THE HARDWARE CONFIGURATION

The figure below depicts the hardware configuration for the facility, with emphasis on the major hardware and human interfaces. At the center of the figure is the ATC host computer. In this case the host is a VAX-11/750. The host is interfaced through a parallel DMA interface to a SANDERS GRAPHIC-7 display computer which drives three calligraphic display indicators simulating the Plan View Display (PVD) available to the air traffic controller. Each controller display has a keyboard associated with it, allowing controller input to the simulation. Two additional DMA interfaces are used for communication between the ATC host and the cockpit simulators. These are designed for message rates of up to 30 Hz each.

The remaining interfaces follow the standard RS232 protocol. The "Command Link" connects the ATC host to the ATC console and allows the experimenter to interface with the simulation control program and create or modify the desired ATC environment for each experiment. The audio link is a two-way communications link used to generate and modify the parameters of the audio subsystem. The audio subsystem is thus automatically controlled by the ATC host. Finally, three two-way communication links are used to drive the pseudo-pilot displays and transmit pseudo-pilot commands to the ATC host.
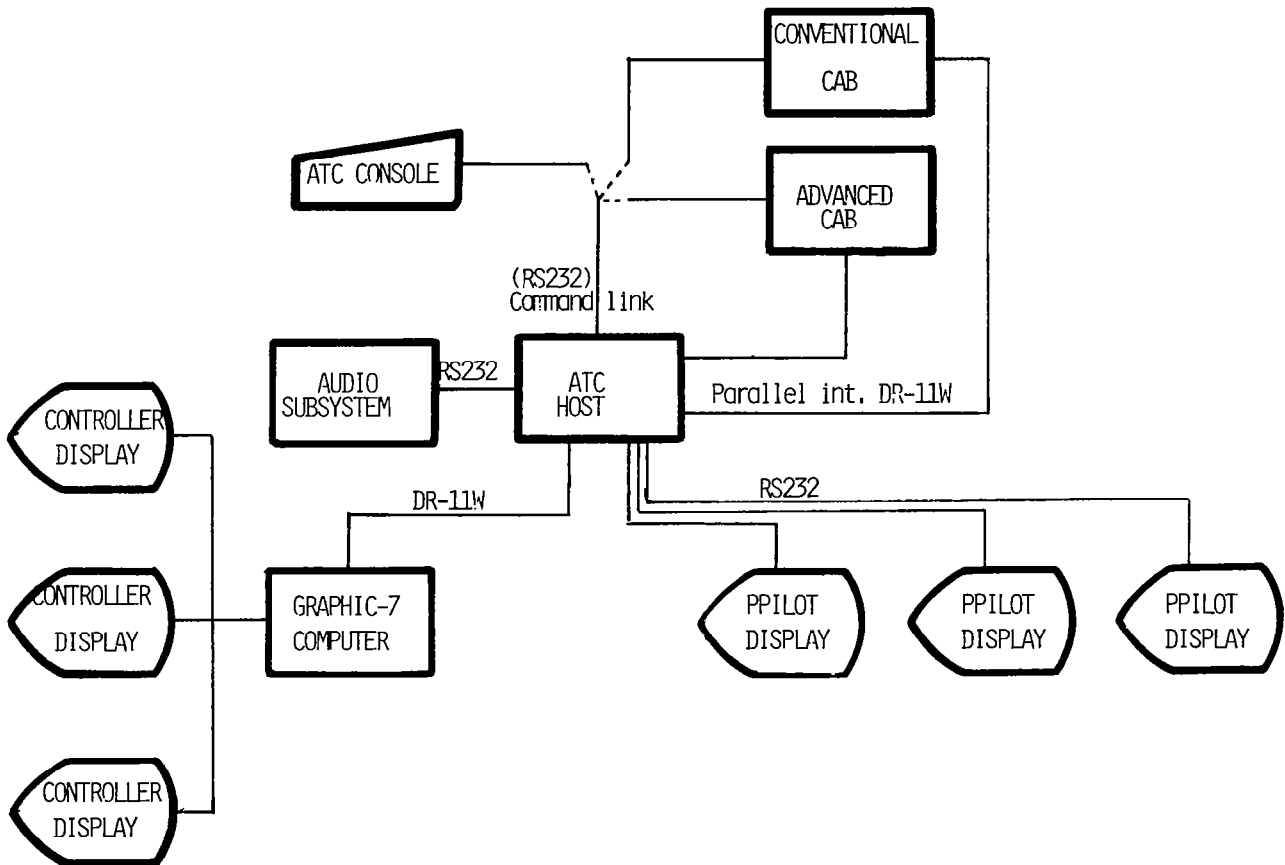


Figure 3.- MVSRF hardware diagram.

# SOFTWARE CONFIGURATION

The ATC simulation facility consists of a number of independent programs. Following the VAX nomenclature, these will be called processes. Each process "knows" how to perform a specific set of tasks. A process can invoke a task by sending an appropriate "message" to the process that knows how to perform it. The target process then responds by performing the task and (if required) replying with a "TASK COMPLETED" message.

This message passing and receiving mechanism is a very powerful tool. It allows a high percentage of the code to be "context-free." This means that one process is not required to know the details of how the task is performed. All it needs to know is how to invoke it. This, in turn, results in simpler code and provides a highly flexible system which is easily amenable to modifications and extensions.

This architecture has another property which is highly desirable for simulating the ATC environment — by the very nature of message passing, all tasks are performed asynchronously. This is consistent with the nature of the ATC system, in which many of the "events" that result in some change in the system are not repetitive (e.g., the aircraft starts climbing whenever the pilot commands it to, manually or through the autopilot, and the latter usually occurs only after the controller clears the aircraft to a different altitude). When two or more tasks have to be performed sequentially, the controlling process (i.e., the one which sends the message) uses the "TASK COMPLETED" message mentioned above as a trigger to dispatch the message to perform the next task in the sequence.

One disadvantage of message passing is that the associated overhead is large when large amounts of data are being passed. To avoid this, "global sections" are used (the name is again borrowed from the standard VAX nomenclature). Global sections are blocks of memory resembling common blocks of standard FORTRAN. The difference is that whereas common blocks are shared by subroutines within the same process, global sections are shared among different processes. Messages therefore only have to include a small number of arguments since the bulk of the data can directly be accessed by the target process through the global sections. As expected, this "optimization" has a price associated with it; the integrity of the data structures has to be maintained at all times. This is particularly true of linked data structures (e.g., lists, stacks, double-ended queues, etc.).

The simulation consists of the following processes: the simulation control (SIMCON), the aircraft position generator (POSGEN), the air traffic controller station driver (SECTOR), and the pseudo-pilot station driver (PPILOT). Each controller station is associated with a distinct "copy" of the SECTOR process and each pseudo-pilot station is associated with a distinct "copy" of the PPILOT process. The complete ATC system therefore will involve eight distinct processes. The accompanying figure depicts the major tasks associated with each process.

SIMCON --  All Communications outside the ATC subsystem
          Simulation timing
          Experimenter command processing
          Script Control
          Audio Control


POSGEN --  Aircraft motion and dynamics
          Airborne Instrument readings
          Ground facilities (Radars, Navaids)


SECTOR --  Controller display generation  (Enroute, Terminal Area, Ground)
          Controller command processing


PPILOT --  Pseudo-pilot display generation
          Pseudo-pilot command processing

Figure 4.- Software components.

## BRIEF DESCRIPTION AND PURPOSE OF THE SCRIPT MECHANISM

The script mechanism allows precisely timed pacing and control of ATCSIM operations while maintaining a flexible override and deviation capability by the simulation actors. Essentially, it allows the "delivery" of text lines to any one of three terminal types: experimenter (command console), controller, and pseudo-pilots. The text lines appear in either specially designated areas of these terminals (information-only lines) or on the terminal's input area.

These text lines are "delivered" upon occurrence of a simulation "event" or the reaching of a certain simulation time. The specifics of this delivery and the text line that must be delivered are given by means of a "script" directive."

Upon delivery to the target terminal, text lines may have one of three functions.

1. The lines may simply show some information to the actor (such as cueing the actor to perform a specified action). Such a script line is termed a "display only" line.

2. The lines may place a command line on the actor's terminal input area, which can be entered by the actor just pressing the "enter" key just as if he/she had keyed in that line. Additionally, the actor may edit the line before entering it or simply cancel the command. Such a script line is termed a "validated" line.

3. Finally, the text may be sent to the terminal for automatic entering, in which case it does not require any actor action (but is logged as if the actor had entered it). Such a line is termed an "automatic" line.

To summarize, a script line is composed of three elements: a "trigger directive," which specifies the event or time that is to cause the script line to be executed; an "action directive," which specifies the target terminal and disposition of the line; and finally, the data itself, or "text," of the script line.

Provides repeatability and controllability of experiments

SCRIPT — a set of "directives" allowing specific actions to occur automatically when certain specified conditions are met

SCRIPT LINE { trigger, action, data

TRIGGER:
(a) timer events
(b) aircraft state events
(c) audio events
(d) named events

ACTION < to whom / how (automatic - validate - display)

DATA    alphanumeric string

Figure 5.- ATC simulation script.

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# REFERENCE

1. Heinz, V.: Stochastic Simulation of Terminal Area Air Space. S. M. Thesis, Mass. Inst. of Technol., Cambridge, June 1976.

# RELATIVE-DATUM LORAN NAVIGATION

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# THE BASIC APPROACH

For short-range navigation around an airport, there are operational and computational advantages in changing the reference frame for Loran navigation for the normal latitude-longitude frame to a tangential local reference plane. This is called "Relative Datum Loran Navigation" since it is centered at a selected reference point (such as a runway touchdown point) whose time differences (TD's) in a given Loran grid have been accurately surveyed.

If the receiver TD's are related to this datum to produce a relative TD ($\Delta$TD), the computation of its position in the x,y local reference plane can be computed easily using two linked linear equations which have four known constant coefficients. We can store the TD's of all touchdown points and these four coefficients in order to provide x,y in local reference planes related to each runway.

. NAVIGATE ON AN EAST-NORTH CARTESIAN GRID AROUND A REFERENCE POINT
  WHOSE TD'S HAVE BEEN ACCURATELY MEASURED

. APPROXIMATE THE HYPERBOLIC GRID WITH AN OBLIQUE RECTILINEAR GRID TANGENT
  TO THE L.O.P.'S AT THE REFERENCE POINT

. USE AS BASIC MEASUREMENTS THE DIFFERENCES BETWEEN THE RECEIVED TD'S
  AND THE PUBLISHED REFERENCE POINT'S TD'S (STD'S)

. THE PROBLEM IS THEN UNIQUELY DETERMINED BY SIX PARAMETERS: $TD_{R1}$, $TD_{R2}$, $A_{12}$
  $A_{11}$, $A_{21}$, $A_{22}$:

$$\begin{Bmatrix} x \\ y \end{Bmatrix} = A \begin{Bmatrix} TD_1 - TD_{R1} \\ TD_2 - TD_{R2} \end{Bmatrix}$$

. THE A'S ARE WEAK FUNCTIONS OF: THE GREAT CIRCLE AZIMUTHS FROM THE
  REFERENCE POINT TO EACH TRANSMITTER, AND THE SIGNAL PROPAGATION VELOCITY

# LOCAL GRID GEOMETRY

The geometry of the Loran-C grid of LOP's can be approximately described as an oblique rectilinear grid whose directions are known. We define unit vectors $\underline{e}_1$, $\underline{e}_2$ as gradients to the LOP's at the grid datum point. The formulation of the receiver position is then derived as shown on the next few figures.
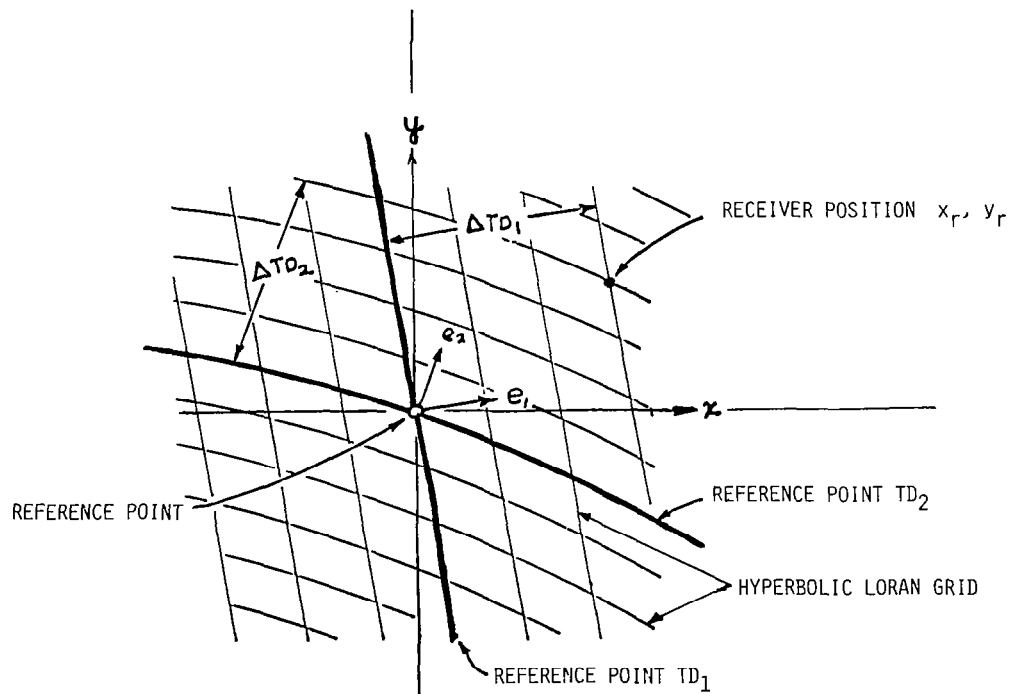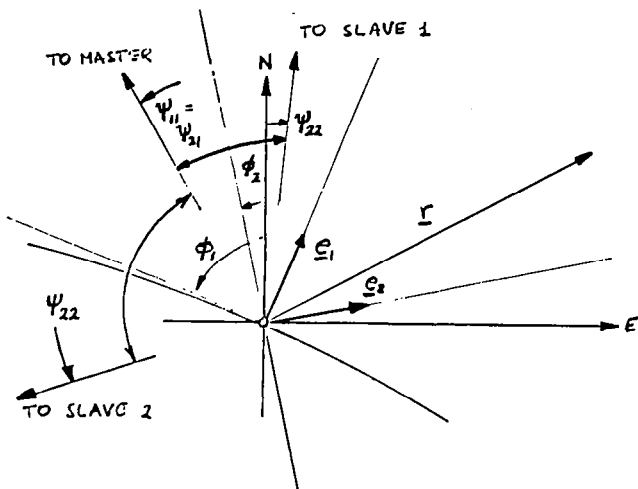
THE BISECTORS OF THE TRANSMITTERS' DIRECTIONS ARE TANGENT TO THE HYPERBOLAS:

$$\phi_1 = 1/2 \ (\Psi_{11} + \Psi_{12})$$
$$\phi_2 = 1/2 \ (\Psi_{21} + \Psi_{22})$$

THE UNIT VECTORS NORMAL TO THE HYPERBOLAS ARE $90°$ TO THE RIGHT OF THE BISECTORS:

$$\underline{e}_1 = \cos\phi_1 \ \underline{i} - \sin\phi_1 \underline{j}$$

$$\underline{e}_2 = \cos\phi_2 \ \underline{i} - \sin\phi_2 \underline{j}$$

THE SPACING BETWEEN THE TRANSMITTERS DIRECTIONS DETERMINES THE GRID GRADIENT:

$$| \ \nabla_1 | = \frac{2\nu}{c} \ \sin \ (\frac{\Psi_{12}-\Psi_{11}}{2}) \qquad | \ \nabla_2 | = \frac{2\nu}{c} \ \sin \ (\frac{\Psi_{22}-\Psi_{21}}{2})$$
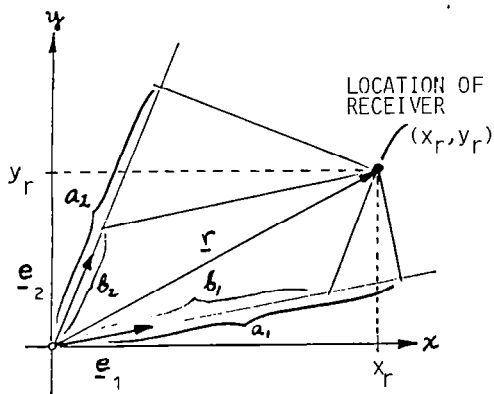


TO FIND THE RECEIVER LOCATION $(x_r, \ y_r)$

$$\underline{r} = b_1\underline{e}_1 + b_2\underline{e}_2$$

Then

$$a_1 = \underline{r}.\underline{e}_1 = b_1\underline{e}_1\underline{e}_1 + b_2\underline{e}_1\underline{e}_2$$
$$a_2 = \underline{r}.\underline{e}_2 = b_1\underline{e}_1\underline{e}_2 + b_2\underline{e}_2\underline{e}_2$$

IF WE DEFINE $\eta = \underline{e}_1\underline{e}_2$,

$$\begin{Bmatrix} a_1 \\ a_2 \end{Bmatrix} = \begin{bmatrix} 1 & \eta \\ \eta & 1 \end{bmatrix} \begin{Bmatrix} b_1 \\ b_2 \end{Bmatrix} , \quad \text{OR} \quad \begin{Bmatrix} b_1 \\ b_2 \end{Bmatrix} = \frac{1}{1-\eta^2} \begin{bmatrix} 1 & -\eta \\ \eta & 1 \end{bmatrix} \begin{Bmatrix} a_1 \\ a_2 \end{Bmatrix}$$

THE RECEIVER LOCATION BECOMES

$$x_r = b_1e_{1x} + b_2e_{2x}$$
$$y_r = b_1e_{1Y} + b_2e_{2Y}$$

## FORMULATION

NOTE THAT $\dfrac{1}{1-n^2}$ = g, GEOMETRIC DILUTION OF POSITION AT THE DATUM

SUBSTITUTING $x_r = \{a_1 - na_2\}\ g\ \cos\phi_1 + \{-na_1 + a_2\}\ g\ \cos\phi_2$

$$= \{\cos\phi_1 - n\cos\phi_2\}\ g\ a_1 + \{-n\cos\phi_1 + \cos\phi_2\}\ g\ a_2$$

SIMILIARLY $y_r = \{-\sin\phi_1 + n\sin\phi_2\}\ g\ a_1 \cdot \{+n\sin\phi_1 - \sin\phi_2\}\ g\ a_2$

NOW $a_1 = \Delta TD_1 \cdot |\nabla_1|$

$a_2 = \Delta TD_2 \cdot |\nabla_2|$

THEREFORE

$$\begin{Bmatrix} x_r \\ y_r \end{Bmatrix} = \begin{bmatrix} \{\cos\phi_1 - n\cos\phi_2\}\ g\ |\nabla_1|, & \{-n\cos\phi_1 + \cos\phi_2\}\ g\ |\nabla_2| \\ \{-\sin\phi_1 + n\sin\phi_2\}\ g\ |\nabla_1|, & \{n\sin\phi_1 - \sin\phi_2\}\ g\ |\nabla_2| \end{bmatrix} \begin{Bmatrix} \Delta TD_1 \\ \Delta TD_2 \end{Bmatrix}$$

$$= \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{Bmatrix} \Delta TD_1 \\ \Delta TD_2 \end{Bmatrix} \quad \text{WHERE } A_{11},\ A_{12},\ A_{13},\ A_{14} \text{ ARE CONSTANTS}$$

# RECTILINEAR GRID ASSUMPTION

The Loran-C grid is actually hyperbolic. There is a geometric error from assuming it to be rectilinear around the datum. For several airports in New England, we can show that the lateral position errors are less than 1° of the runway heading within 20 kilometers of the airport. At 10 kilometers, the lateral errors are less than 70 meters. At 5 kilometers, they are less than 15 meters. It will be necessary to choose a good geometry for every airport, and to study these errors at airports in other parts of the US.

LATERAL POSITION ERROR DUE TO RECTILINEAR GRID APPROXIMATION
FOR STATION PAIRS (NANTUCKET-SYRACUSE, CARIBOU-SYRACUSE)

B1 -- Burlington, 270°
B2 --      " , 180°
M1 -- Montpelier, 270°
M2 --      " , 180°
P1 -- Portland, 270°
P2 --      " , 180°
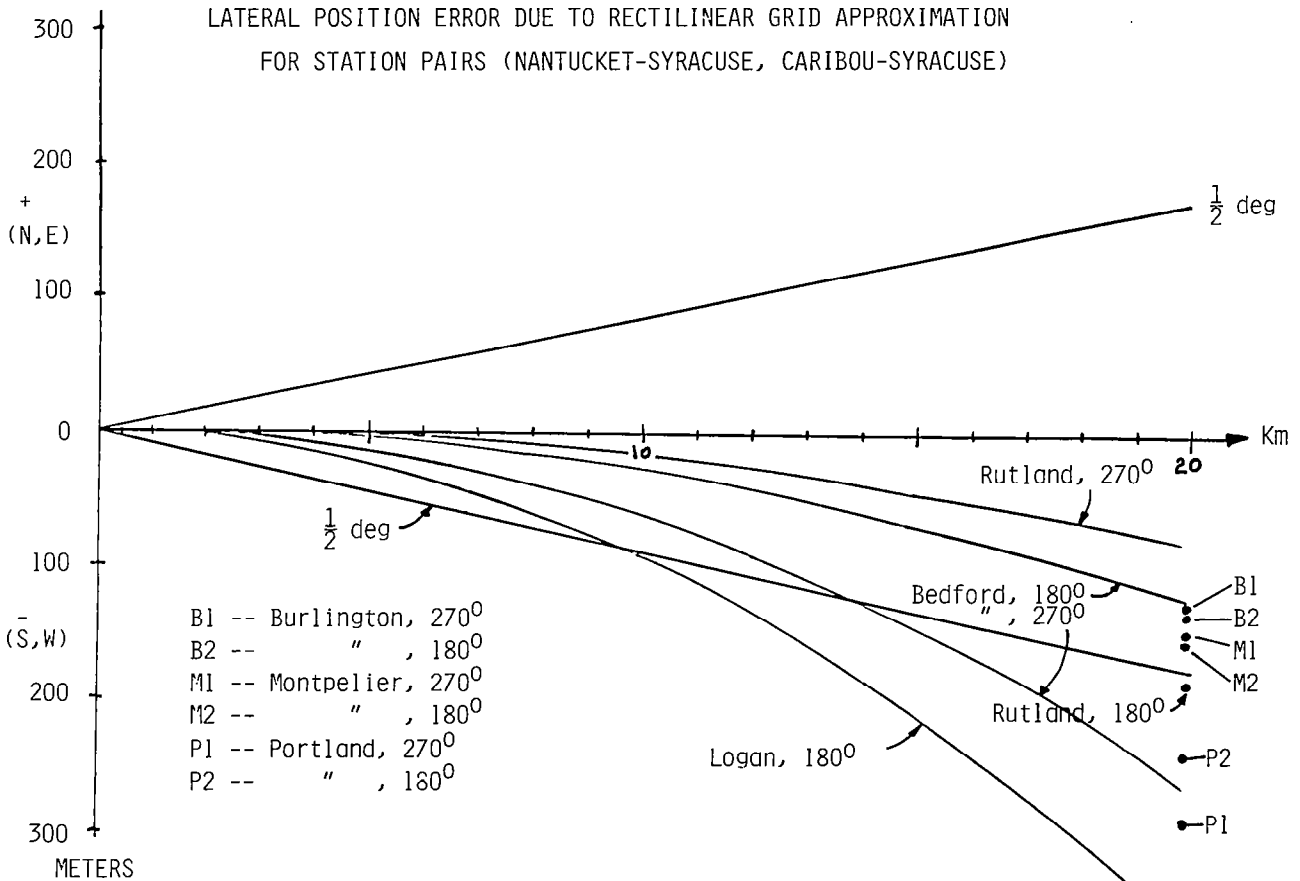
## MERITS

- FIRST-ORDER EFFECTS OF THE ERROR IN MODELING SIGNAL PROPAGATION VELOCITY "COMMON-MODE" OUT OF THE PROBLEM (SECOND-ORDER EFFECTS REMAIN)

- THE APPROACH IS INDEPENDENT OF LATITUDE-LONGITUDE CONVERSION ALGORITHMS

- THE COMPUTATION REQUIREMENTS ARE REDUCED TO FOUR MULTIPLICATIONS, TWO ADDITIONS, AND TWO SUBTRACTIONS PER FIX, AND MAY BE CARRIED OUT IN (SCALED) FIXED POINT

- ALL THE DATA REQUIRED TO FULLY DEFINE ONE REFERENCE POINT CAN BE STORED IN 80 BITS (10 BYTES)

- IF FED THE RATE OF CHANGE OF THE TD's (AVAILABLE DIRECTLY FROM MOST SIGNAL TRACKING LOOPS), THE METHOD WILL COMPUTE $\dot{x}$, $\dot{y}$ WHICH CAN BE USED IN PATH GUIDANCE

## OPEN QUESTIONS

- WHAT IS THE MAGNITUDE OF THE ERROR INDUCED BY THE RECTILINEAR-GRID APPROXIMATION AT AIRPORTS IN OTHER AREAS OF USA?

- WHAT ARE THE EFFECTS (THROUGH THE A's) OF ERRORS IN THE KNOWLEDGE OF AZIMUTH DIRECTION OF THE TRANSMITTERS AND PROPAGATION VELOCITY?

- WILL IT WORK IN ACTUAL PRACTICE?

- WHAT ARE THE ADVANTAGES OF A SECOND-ORDER MODEL OF THE FORM?

$$\begin{Bmatrix} x \\ y \end{Bmatrix} = [A] \begin{Bmatrix} \Delta TD_1 \\ \Delta TD_2 \end{Bmatrix} + [E] \begin{Bmatrix} \Delta TD_1^2 \\ \Delta TD_2^2 \end{Bmatrix}$$

# Princeton
# University

# INVESTIGATION OF AIR TRANSPORTATION TECHNOLOGY

## AT PRINCETON UNIVERSITY, 1982

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## SUMMARY OF RESEARCH

The Air Transportation Technology Program at Princeton University, a program emphasizing graduate and undergraduate student research, proceeded along six avenues during the past year:

- Investigation of Fuel-Use Characteristics of General Aviation Aircraft

- Experimentation with an Ultrasonic Altimeter

- Single-Pilot Instrument Flight

- Application of Fiber Optics in Flight Control Systems

- Voice Recognition Inputs for Navigation/Communication Receiver Tuning

- Computer-Aided Aircraft Design

Principal investigator Robert Stengel worked with Profs. Larry Sweet and H.C. Curtiss in advising the students participating in this program.

Navigation research conducted during earlier years provided a logical stepping stone to consideration of flight management systems for general aviation aircraft, including fuel-minimizing guidance between origin and destination points. The effectiveness of such guidance logic is, of course, dependent on the accuracy of aircraft fuel use models, and this, in turn, requires adequate mathematical description of engine characteristics. In his doctoral research, Richard Parkinson developed a cruise performance model that can be developed from operating handbook data, and he developed a detailed mathematical model of the fuel use characteristics of general aviation reciprocating engines. Final results are documented in his thesis[1]. Mr. Parkinson began his research under the guidance of Prof. Dunstan Graham, who retired from the university in 1980; he continued with the supervision of Profs. Curtiss and Sweet. Working with Prof. Curtiss, graduate student Eugene Morelli is continuing this research.

Several students have studied the feasibility of using an ultrasonic transducer as an altimeter for the landing approach through touchdown. The transducer, initially developed for use in an automatic range-finding camera, demonstrated better than 1% accuracy for ranges of 0.27 to 10.67 m (0.9 to 35 ft) in laboratory and wind tunnel tests, with transverse air velocities of up to 45.7 m/sec (150 ft/sec) and with sensor angles of 0 to 25 deg. Following last year's work by Amy Snyder, senior Philip Chu was able to increase the measurement range to 56 ft by modifications to the device's circuitry{2}; the changes made the device more susceptible to wind-induced noise. Patricia Corvini, a junior in electrical engineering and computer science, investigated a microprocessor-based correlation technique for improving the measurements when the signal-to-noise ratio is low{3}. The processing principle was verified, although the implementation was not suitable for real-time application.

The Flight Research Laboratory completed a study of flying qualities criteria for single-pilot instrument flight operations, culminating in the Ph.D. thesis of Aharon Bar-Gill{4}. Techniques for applying extended optimal smoothing to sequential DME data and on-board inertial and air data were developed and applied to flight test data. In this approach, a single DME receiver is switched between alternate DME stations to update the state estimate, which is processed after the flight has been completed. Because all the measured data are applied to estimate the state at each point in the flight path, the result is somewhat more accurate than that which would be obtained from the extended-optimal filter. Experimental results yielded quantitative indicators of pilot performance and workload as functions of the aircraft's long-period longitudinal dynamic characteristics.

Fiber optic data transmission promises to provide decreased weight, improved resistance to electro-magnetic interference, and increased reliability in future active flight control systems. Graduate student Kristin Farry is nearing completion of an application of fiber-optic technology in a multi-microprocessor system. Princeton's Variable-Response Research Aircraft (VRA) has dual angle-of-attack and sideslip-angle vanes mounted at each wingtip, previously connected to the central analog and digital control logic by standard wiring{5}. Dual microprocessors have been installed at the wingtips; the sensors are connected directly to these units, which in turn communicate with the central microprocessor via fiber optic links. The local processors provide scaling and instrument error correction, elimination of roll rate effects on sensed angles, and analog/digital conversion before sending the data to the flight control computer unit. The fiber optic multiprocessor system has been tested in flight, and the results will be presented in Ms. Farry's M.S.E. thesis.

Voice recognition of pilot inputs could play a major role in future air transportation, not only for commercial aircraft but for general aviation aircraft as well. This capability has

particular significance for single-pilot instrument flight operations, where one pilot is required to perform all the tasks normally carried out by two or three persons in the larger aircraft. The tasks that could be carried out using voice command are varied; as a generality, these are characterized as the jobs which a captain might ask the co-pilot to do (e.g., tuning radios, maintaining contact with air traffic control, holding altitude, and so on). Frances Koo, a senior in electrical engineering and computer science, completed a project in preparation for voice recognition tuning of the navigation and communication receivers in Princeton's Avionics Research Aircraft (ARA){6}. This work is being continued in the Ph.D. research of Chien Huang. The ARA's DME receiver has been tuned in flight by digital signals from a microprocessor, which received inputs from the pilot via the voice recognition board{7}. Initial developments are being extended to include the tuning of VOR and communications receivers, as well as the statistical evaluation of the system when used with different vocabularies, operators, and background noise conditions.

Work was begun on the Princeton Aircraft Design System (PADS), a modular interactive graphics computer program for the design of aircraft. The objective is to facilitate the design of aircraft configurations ranging from general aviation and glider aircraft to supersonic transports and other high-performance aircraft. Four students produced reports on various aspects of the PADS computer program, which is implemented in the APL computer language using Princeton University's IBM 3081-based Interactive Computer Graphics Laboratory facilities{8-11}. Seniors Thomas Edwards, James Gerber, and Marina Vogel respectively worked on preliminary design, internal geometry, and graphical input. Junior Brian Holasek began development of the wing geometry and aerodynamics module.

The NASA grant supporting student research in air transportation technology has inestimable value in helping educate a new generation of engineers for the aerospace industry, and it is producing research results that are relevant to the continued excellence of aeronautical development in this country.

# REFERENCES AND ANNOTATED BIBLIOGRAPHY

1.  R.C.H. Parkinson, "A Fuel-Efficient Cruise Performance Model for General Aviation Piston Engine Airplanes", Princeton University Ph.D. Thesis, No. MAE 1527-T, June 1982.

    This dissertation presents a fuel-efficient cruise performance model that maximizes the specific range of airplanes powered by spark-ignition piston engines and propellers. The uses and limitations of typical pilot operating handbook cruise performance data for constructing cruise performance models are first examined. These data are found to be inadequate for constructing such models. A new model consisting of two subsystems is developed. The new model facilitates the maximization of specific range; by virtue of its simplicity, it appears suitable for airborne implementation.


2.  P.C. Chu, "Ultrasonic Altimetry: Final Report, Enhanced Range Capability; The Modified Polaroid Ranging System", Princeton University Independent Work Report, Dec 1981.

    This report studies the feasibility of using the Polaroid Ultrasonic Ranging System as an altimeter for landing aircraft during the final approach and flare maneuver. Using an external processing circuit and time-stepped gains, fairly reliable ranging could be obtained up to a minimum of 50 ft. The two factors that appear to limit the ranging system are the signal-to-noise ratio and the "chirp" volume of the transducer.


3.  P. Corvini, "Hardware and Software for a Feasibility Study of Cross-Correlation for Extending the Range of an Ultrasonic Ranging System", Princeton University Independent Work Project, May 1982.

    The aim of this work was to provide an inexpensive means of determining if digital correlation analysis could be used to extend the usable range of an ultrasonic ranging system. The system consisted of the existing sensor, the modified circuit board described above, a breadboard timing circuit, and three Multibus$^{TM}$ microcomputer boards. The ultrasonic chirp consisted of 56 cycles emitted at 50 to 60 Hz; data from several chirps were combined to get a composite picture of a single chirp, using an analog/digital converter operating at 28 Hz. The system allowed sixteen shifted passes at 10 Hz for an effective rate of 160 Hz.

4. A. Bar-Gill, "Longitudinal Flying Qualities Criteria for Single-Pilot Instrument Flight Operations", Princeton University Ph.D. Thesis, No. MAE 1576-T, Oct 1982.

This research used estimation and control theory, flight testing, and statistical analysis to deduce flying qualities criteria for general aviation single-pilot instrument flight rule (SPIFR) operations. The principal concern was that unsatisfactory aircraft dynamic response combined with high navigation/communication workload can produce problems of safety and efficiency. The objective was achieved by flying SPIFR tasks with different longitudinal dynamic configurations (using the variable-stability features of the test aircraft) and by assessing the effects of such variations on pilot opinion and performance. The experimental results yielded quantitative indicators of pilot performance and workload, and for each of them, multivariate regression was applied to evaluate candidate flying qualities criteria. Results indicated that phugoid mode damping, stick force sensitivity, and pitch attitude sensitivity were the most significant flying qualities parameters for these tasks. In the course of the research, a numerically robust algorithm for flight path reconstruction was developed. This nonlinear optimal smoothing algorithm used multiple, scanned DME measurements in combination with aerodynamic and inertial data to provide highly accurate position, velocity, and angular estimates.

5. K.A. Farry and R.F. Stengel, "Distributed Processing and Fiber Optic Communications in Air Data Measurement", Proceedings of the 1982 National Aerospace and Electronic Systems Conference, Dayton, May 1982.

This paper describes the application of distributed processing, fiber optics, and hardware redundancy to collecting air data. Microprocessor-controlled instrumentation packages in each wingtip of Princeton's Variable-Response Research Aircraft (VRA) collect angle-of-attack and sideslip-angle data in digital form. After scaling, filtering, and calibrating the data, the wingtip processors send the data to the central processor, located in the VRA's fuselage, via fiber-optic links. The system design is presented, and results of a preliminary flight test are discussed. During this flight, over 2000 data transmissions occurred without error. The technology shows considerable promise for enhancing the reliability and performance of future flight control systems.

6. F. Koo, "An Application of Voice Recognition: Frequency-Tuning On Board an Airplane", Princeton University Independent Work Report, May 1982.

The objective of this work is to develop a system for tuning aircraft radios using voice inputs. The report presents an overview of voice recognition technology, and it identifies factors to be considered in experimentation. The voice recognition system is described. It consists of a commercially available voice recognition module, a host microcomputer, and the digital interface to aircraft radios. The system is capable of recognizing 100 words, which are then used to control the tuning function.

7. "Filter Center", Aviation Week & Space Technology, Vol. 117, No. 15, Oct. 11, 1982, p. 135.

Princeton University is exploring use of voice-recognition techniques as a potential 'electronic co-pilot' for general aviation aircraft under sponsorship of NASA's Langley Research Center. Current tests on board a Ryan Navion are using an Interstate Electronics CRM-102 voice-recognition system in which the pilot tunes Bendix BX-2000 distance measuring equipment by speaking the name or identification letters of a Vortac station. After training to a specific pilot's voice prior to takeoff, the system achieves about 95% successful recognition of commands and no false recognitions.

8. T.A. Edwards, "A User's Guide to the Preliminary Design Module of the Princeton Aircraft Design System", Princeton University Independent Work Report, May 1982.

The PADS Preliminary Design Module is an integrated system of APL computer programs with the capability to size and/or optimize an airplane to meet an arbitrary number of constraints. The package doubles as the initiator of PADS, and as an independent learning tool for decision-making in the conceptual stage of airplane design. Four design parameters were selected as the most representative performance "drivers": wing aspect ratio, sweep angle, wing loading, and thrust loading. The design module permutes these parameters and determines the resultant "point" designs.

9.  J. Gerber, "Princeton Aircraft Design System (PADS) -- Internal Geometry Module: A Step in the Realization of Computer-Aided Engineering for Aircraft Design", Princeton University Independent Work Project, May 1982.

    With the use of fast computer graphics, designers have become capable of describing complex, three-dimensional objects for drafting reproduction in one half to a quarter of the time required for conventional drafting techniques. These same computer-aided design advantages can be brought to bear on the integrated design of aircraft. The PADS internal geometry module is one element of such a system, providing the mechanism for defining the geometries of specific components including the description of line segments, component attributes, and component assemblies. The module provides a 3-D representation of a component or assembly that can be rotated, projected, or transformed to meet specific requirements. The package is "menu-driven", providing the user with relevant "help" information, as required.

10. B. Holasek, "PADS: Wing and Tail Geometry, Wing Section with Data Base for Design Support", Princeton University Independent Work Project, May 1982.

    This is an interim report describing accomplishments during the first term of a two-term project. Airfoil and wing planform characteristics are defined and calculated, and the results can be viewed in two or three dimensions. Future features will include the estimation of wing aerodynamic characteristics and the graphical mating of the wing to the fuselage.

11. M.H.C. Vogel, "Princeton Aircraft Design System: Graphical Input and Modification of Data Bases", Princeton University Independent Work Report, May 1982.

    A package for input and manipulation of data bases was defined, and coding was begun. Objects can be described using input from a terminal keyboard or a digitizing pad, and editing capabilities are provided.

# COCKPIT VOICE RECOGNITION PROGRAM AT PRINCETON UNIVERSITY

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OVERVIEW

- Today's Technology

        The voice recognition is a fairly new technology.
Although not as mature as the voice synthesis, it is able to
offer limited-vocabulary low-error-rate modules.  There are
numerous commercially available boards; most of them (if not
all) use frequency division technique (to be explained later)
to achieve recognition.

- Advantage of vocal over manual input

        Vocal input is superior to the manual one in situations
where eye-hand coordination is not feasible or difficult.  By
resorting to verbal commands, a person is actually using a
familiar input mode which has the additional advantage of speed.

- Current Research Effort

        Current research on voice recognition is being carried
out at NASA Ames and Langley Research Centers.  Quite a few
masters theses have been written on the performance of a voice
recognition device at the Naval Postgraduate School.  The Army
has conducted related work on helicopters.

- Objective of Princeton University's Study

        The objective of Princeton University's Flight Research
Laboratory is to find applications of voice recognition technology
(VRT) to the aeronautics, particularly on the pilot workload
alleviation.  We believe that the VRT does not have to prove its

maturity any longer.     We believe that time has come for us
to use its unproven capabilities in the cockpit environment.
We have elected to demonstrate the feasibility of voice tuning
of radio and DME since it has immediate advantages to the
pilot and it can be completed in a reasonable time.

## OVERVIEW

- TODAY'S TECHNOLOGY

- ADVANTAGE OF VOCAL OVER MANUAL INPUT

- CURRENT RESEARCH EFFORT  (AT NASA, NAVY, ARMY, ... )

- OBJECTIVE OF PRINCETON UNIVERSITY'S STUDY

## SYSTEM BLOCK DIAGRAM

The Voice Recognition System at Princeton's Flight Research Laboratory consists of a Z80 CPU which uses two serial ports and one parallel I/O port to establish communication with CRT, VRM, DME and NAV/COM units, as shown in the figure. The DME and NAV/COM are part of Bendix 2000 product line. They provide digital I/O for easy interfacing. The VRM is an Interstate Electronics Voice Recognition Module 102. Details of this board follow.

```
                              ┌──────┐
                         ↗    │ CPU  │   ↖
                       ↗      └──┬───┘     ↖
                     ↗          ⇕            ↖
                   ↗            ⇕              ↖
          ┌──────┐ ↗      ┌──────────┐   ┌──────────┐   ┌──────────┐
┌────────┐│      │        │ PARALLEL │   │  SERIAL  │   │  SERIAL  │
│NAV/COM │◁─────▷│        │   I/O    │   │   I/O    │   │   I/O    │
└────────┘                └────┬─────┘   └────┬─────┘   └────┬─────┘
                               ⇕              ⇕              ⇕
                          ┌────────┐     ┌────────┐     ┌────────┐
                          │  DME   │     │  VRM   │     │  CRT   │
                          └────────┘     └────────┘     └────────┘
```
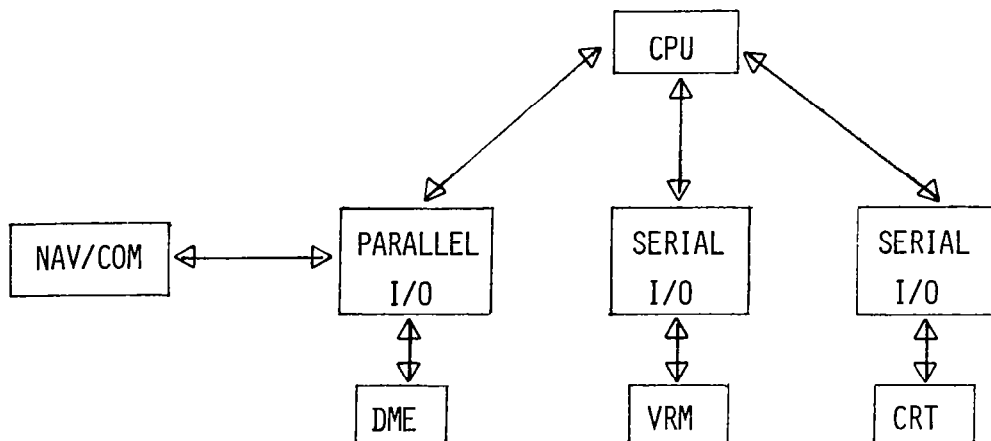
## VRM SIMPLIFIED FUNCTIONAL DIAGRAM

The VRM board processes the speech by determining
the energy content at discrete frequency intervals. As can
be seen from the figure, the speech is first equalized so
that a stronger voice is treated in the same way as a weak
one. The preamplifier is optional since some mikes have
built-in preamps. The speech then passes through a bandpass
filter bank whose output is digitally encoded and stored in
the 2K x 8 RAMS. The VRM communicates with a host processor
via either serial or parallel lines. The ROM shown contains
the program that controls the voice recognition process,
including pilot cueing, logical response to identified words,
and receiver tuning.

DATA/ADDRESS BUS

SPEECH SPECTRUM EQUALIZER

OUT / IN

PREAMPLIFIER

SPEECH SIGNAL

FILTER NETWORK
ANALOG MUX
A/D (8 BITS)

MICRO-PROCESSOR

40 WORDS    RAM 2K x 8 (STANDARD)

100 WORDS   RAM 2K x 8 (OPTIONAL)

6802 CPU

ROM 4K x 8

PARALLEL I/O  PORT A
8 DATA IN
8 DATA OUT    TO
4 HANDSHAKING HOST
CONTROL

SERIAL I/O  PORT 1
7  TO/FROM HOST

PARALLEL I/O  PORT B
8 USER CONTROL
8 TTL AND/OR
ONBOARD
SWITCHES

SERIAL I/O  PORT 2
7  TO KEYBOARD/
DISPLAY

(From ref. 1)

## FIRST FEASIBILITY TEST

Our first feasibility test was carried out on September 17, 1982 when we performed in-flight tuning of the DME. That flight test had the sole purpose of demonstrating that voice-recognition is viable in a noisy cockpit environment; therefore the vocabulary was kept to only six words: "over, tune, Robbinsville, Colts Neck, Yardley, Solberg". After reporting our success in the last Quarterly Report[1], we set three goals: test the VRM with vocabulary of 40 words or more (which we did); identify and implement potential pilot tasks whose workload can be alleviated by a voice system (which we have partially completed); and study the scenario of a vocally interactive pilot-airplane configuration (which remains to be done).

---

[1]Joint University Program Quarterly Review, held at the Massachusetts Institute of Technology, Oct. 1, 1982.


FIRST FEASIBILITY TEST:  IN-FLIGHT DME TUNING
(SEPT. 17, 1982)
(LIMITED VOCABULARY)

GOALS SET:  • TEST THE VRM WITH VOCABULARY OF 40 WORDS
OR MORE


• IDENTIFY (AND IMPLEMENT) POTENTIAL PILOT
TASKS WHOSE WORKLOAD CAN BE ALLEVIATED
BY A VOICE SYSTEM


• STUDY THE SCENARIO OF A VOCALLY INTER-
ACTIVE PILOT-AIRPLANE CONFIGURATION

## VOCABULARY

The vocabulary we chose as a first cut consists of
words that are meaningful for pilots to use in the cockpit.
We feel that the presence of every word in the vocabulary
should be justified.  Therefore we see that, as we go down
the list, the numbers (0 - 9) are there for obvious reasons.
"Point (.)" is used to denote decimals.  The word "tune" is
the first word given for radio or DME tuning command.
"RBV" (Robbinsville), "CTK" (Colts Neck), "YRD" (Yardley)
are three arbitrary DME stations; the stations can be
altered according to the need.  "Exit" is used to exit the
recognition mode, as is the word "quit".  "Delete" is needed
to correct a wrong input (say the last of a string of numbers).
"Sleep" is to tell the computer to go into hibernation mode
to be awakened only by the command "Wakeup".  These are useful
when the pilot desires to converse with others without leaving
the recognition mode.  "Run" is to denote the beginning of an
experiment, as in "Run" "Number",,,.  "Execute" tells the
machine to execute the command.  "COM1", "COM2","NAV1", "NAV2"
and "DME" are addressable equipments.  "Over" may be used to
denote the end of a sub-command.  "Turn" is used with the
other four words, "Right", "Left", "On", and "Off" to perform
indicated functions.  "Change" is used to modify something
like "Frequency" or "Airspeed".  "Knots" is needed to specify
an airspeed value.  Similarly "Altitude" is used together with
"Thousand", "Hundred" and "Feet"  to command the aircraft to
"Climb-to" or "Descend-to" or "Hold" certain altitude.  Finally,
"Heading" is used together with "North", "West", "South", and
"East" to perform changes in the airplane's direction.

# VOCABULARY

| | | | | | | |
|---|---|---|---|---|---|---|
| 0. | ZERO | 15. | EXIT | 30. | TURN | 45. | WEST |
| 1. | ONE | 16. | DELETE | 31. | RIGHT | 46. | SOUTH |
| 2. | TWO | 17. | ABORT | 32. | LEFT | 47. | EAST |
| 3. | THREE | 18. | SLEEP | 33. | ON | 48. | CLIMB-TO |
| 4. | FOUR | 19. | WAKEUP | 34. | OFF | 49. | DESCEND-TO |
| 5. | FIVE | 20. | QUIT | 35. | CHANGE | 50. | HOLD |
| 6. | SIX | 21. | RUN | 36. | FREQUENCY | | |
| 7. | SEVEN | 22. | NUMBER | 37. | AIRSPEED | | |
| 8. | EIGHT | 23. | EXECUTE | 38. | KNOTS | | |
| 9. | NINE | 24. | COM1 | 39. | ALTITUDE | | |
| 10. | . (POINT) | 25. | COM2 | 40. | HUNDRED | | |
| 11. | TUNE | 26. | NAV1 | 41. | THOUSAND | | |
| 12. | RBV | 27. | NAV2 | 42. | FEET | | |
| 13. | CTK | 28. | DME | 43. | HEADING | | |
| 14. | YRD | 29. | OVER | 44. | NORTH | | |

## DESIRABLE PERFORMANCE TEST OF VRM

After reviewing the literature on voice recognition
and utilizing some common sense and intuition, we arrived at
a set of tests which ought to be conducted on any voice
recognition system (so that the users become familiar with
the performance of their module which is different from one
unit to another).

The first test one would like to carry out is probably
the error rate test; that is, what percentage of the time does
the system misrecognize the words spoken. This should be
distinguished from the rejection rate, where the system does
not recognize the word and rejects the input as invalid. The
error rate test should be performed under various conditions,
such as in quiet and noisy environment, with and without the
noise canceller. The second test concerns the error rate as
a function of training passes. This will help the users to
determine the optimal number of training passes to achieve
the lowest error rate. The third test is designed to see if
a female voice would have more or less problem than that of
male voice. The fourth test is important when it is desirable
to limit some users' functional access. Suppose only one
person is allowed to command the system (by voice) to perform
a specific task. We would like the system to reject other users
from this unauthorized command; hence, the need to learn how
well the VRM performs as far as speaker differentiation is
concerned. The fifth test is related to rejection rate, which
determines how high the threshold level should be set. The
threshold level is the minimum score that an utterance must
get in order to be declared a valid word. The higher we set
the level, the higher the score (and the lower the error rate),

and vice versa.  Clearly there is an optimum setting that must
be determined from the experiments.  The last interesting test
is to check how the system performs with several different lan-
guages in the same vocabulary.  Most systems are language-
independent; however, there are languages or sounds that are
better suited for VRM than others.

## DESIRABLE PERFORMANCE TESTS OF VRM

1. ERROR RATE (WITH AND WITHOUT NOISE CANCELLER)
   IN QUIET AND NOISY ENVIRONMENT

2. ERROR RATE VS. TRAINING PASSES

3. FEMALE VS. MALE VOICE

4. SPEAKER DIFFERENTIATION

5. OPTIMUM TRESHOLD LEVEL (REJECTION RATE)

6. MULTILINGUAL MODE

## RESULTS ERROR RATE

This figure shows the statistics we have gathered for error rate. The subject item "without canceller" means test was conducted in a quiet laboratory environment whereas the "with canceller" means the test was given inside our Navion cockpit which has a noise cancelling microphone. It turned out that we had some setup problems with the latter case (electrical interference) so its results are somewhat misleading.

The experiment consists of having the subjects train the VRM for a number of times using the previous vocabulary. The VRM then was put into recognition mode and the subjects would read back the entire vocabulary once; thereafter, they would randomly pick words to say.

From the results displayed on the figure, we see that the error rate does not seem to decrease with the number of trainings. This is because the subjects, as they used the system and became more familiar with it, tended to repeat the words that were incorrectly recognized and therefore involuntarily increased the error rate. The higher error rate of subject D relative to other three should not be taken to mean poorer VRM performance with a female voice, since one sample is hardly conclusive.

## RESULTS - ERROR RATE

| | 3 TRAININGS | 5 TRAININGS | 7/8 TRAININGS |
|---|---|---|---|
| **SUBJECT A:** | | | |
| WITHOUT CANCELLER | 1.22% | 2.94% | 4.76% |
| WITH CANCELLER | 3.% | 4.5% | 6.58% |
| | | | |
| **SUBJECT B:** | | | |
| WITHOUT CANCELLER | 1.22% | 1.26% | 3.5% |
| WITH CANCELLER | 6.25% | 1.% | 3.26% |
| | | | |
| **SUBJECT C:** | | | |
| WITHOUT CANCELLER | 1.1% | 0.% | 1.8% |
| WITH CANCELLER | 2.% | 6.4% | 7.14% |
| | | | |
| **SUBJECT D: (FEMALE)** | | | |
| WITHOUT CANCELLER | 8.53% | 5.06% | 9.86% |

## RESULTS - REJECTION RATE

The effect of number of trainings is most pronounced in the case of rejection rate. We see a clear downward trend as the number of trainings is increased. This is true both with and without noise cancelers. A few more experiments should be performed in order to determine the optimum training passes and concurrently the ideal threshold level.

|  | 3 TRAININGS | 5 TRAININGS | 7/8 TRAININGS |
|---|---|---|---|
| SUBJECT A: |  |  |  |
| WITHOUT CANCELLER | 8.2% | 4.4% | 0.% |
| WITH CANCELLER | 7.7% | 0.% | 1.3% |
| SUBJECT B: |  |  |  |
| WITHOUT CANCELLER | 17.% | 5.06% | 3.5% |
| WITH CANCELLER | 15.% | 11.% | 4.3% |
| SUBJECT C: |  |  |  |
| WITHOUT CANCELLER | 25.8% | 8.8% | 3.6% |
| WITH CANCELLER | 34.% | 17.% | 4.28% |
| SUBJECT D: (FEMALE) |  |  |  |
| WITHOUT CANCELLER | 40.% | 6.33% | 9.86% |

SUMMARY

We can summarize our work as follows:

1. Voice recognition is a rapidly maturing technology, and speaker-dependent systems have become a commercial reality.

2. Voice recognition is a viable avionic tool, despite the aircraft noise, and it can be utilized to alleviate pilots' workload.

3. Performance of a current voice recognition module depends on choice of vocabulary, training, and speaker. This means that we can optimize the system by a sound combination of the factors mentioned.

- VOICE RECOGNITION IS A RAPIDLY MATURING TECHNOLOGY

- VOICE RECOGNITION IS A VIABLE AVIONIC TOOL

- PERFORMANCE OF CURRENT VRM DEPENDS ON CHOICE OF VOCABULARY, TRAINING AND SPEAKER.

## FUTURE WORK

Our future work will be targeted at:

1. Modification and refinement of vocabulary. This means further testing in a feedback loop.

2. Completion of voice-tuning of NAV/COM UNIT. This work is almost finished. The next step is to check that it functions properly.

3. Identification of additional workload education capability of voice recognition within the cockpit will be conducted. One day we will be able to not only fly by wire but also fly by voice.

● MODIFICATION AND REFINEMENT OF VOCABULARY

● COMPLETION OF VOICE - TUNING OF NAV/COM UNIT

● IDENTIFICATION OF ADDITIONAL WORKLOAD REDUCTION CAPABILITY OF VOICE RECOGNITION WITHIN COCKPIT.

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# DISTRIBUTED PROCESSING AND FIBER OPTIC COMMUNICATIONS

## IN AIR DATA MEASUREMENT[*]

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## ABSTRACT

This paper describes the application of distributed processing, fiber optics, and hardware redundancy to collecting airstream data in Princeton's digitally controlled Variable-Response Research Aircraft (VRA). Microprocessor-controlled instrumentation packages in each wingtip of the aircraft collect angle-of-attack and sideslip data in digital form; after scaling, filtering, and calibrating the data, they send it to the aircraft's microprocessor Digital Flight Control System (micro-DFCS) via digital fiber optic data links. Each wingtip's package is independent of the other; therefore, the system has dual hardware redundancy. The fiber optic link design is presented as well as a description of the calibration and communications software. Translation of the system's dual redundancy into fault tolerance is also covered. Results of preliminary flight tests are included.

## INTRODUCTION

The Flight Research Laboratory at Princeton University has undertaken a research program that focuses on the development of multi-microprocessor flight control systems for future aircraft. In the past, our attention was directed at new methodologies for digital control system design and at developing the capability to test advanced hardware and software in flight. More recently, we have addressed technology that eventually will lead to "fly-by-light" and distributed processor systems.

This paper describes an angle of attack and sideslip data collection and calibration system that has two independent microprocessor-based units. The data are transmitted from these calibration units to the aircraft's digital flight

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control system in ready-to-use form via a fiber optic bus. The micro-DFCS uses the system's dual redundancy to make judgements on information quality before using the data as inputs to the flight control computations. This system incorporates three important new flight control technologies — distributed processing, fiber optic communications, and fault tolerance.

An overview of the system is presented first, followed by a description of the hardware used. The fiber optic link design is discussed in particular detail. Software design is detailed next, in three parts — data preparation, communications, and redundancy management. Finally, the status of the system testing is described, along with an outline for the remainder of the test program.

## SYSTEM DESCRIPTION

Two air data sensor vanes — measuring angle of attack and sideslip angle — are mounted at each wingtip of the aircraft. Their unusual position represents a tradeoff between the aircraft's structural rigidity and airstream distortion. Unfortunately, this location puts the vanes in the vicinity of the wingtip vortex, which makes calibration of the data more difficult than with conventional air data sensor booms.

The sensors deliver analog signals (electrical voltages) to the wingtip microprocessor packages (WIMP), each one of which contains a multiplexed A/D unit, a CPU, memory, and a fiber optic communications interface mounted in an STD bus. In the WIMP, the sensors' analog output signals are converted to digital format. Signal noise and other unwanted contributions, such as upwash and roll-rate effects are eliminated from the raw data by software-implemented filtering and calibration, so that each wingtip sensor unit's data are independent of the other's. Roll rate and velocity signals for these calculations must come from the micro-DFCS central information package. This, as well as communications "handshake", requires two-way communication between the WIMPs and the micro-DFCS. After filtering and calibration in each WIMP, the data are transferred via the fiber optic data link to the aircraft's digital flight control system. The data's validity is determined by comparing the results from each wingtip. This signal flow is outlined in Figure 1.

Before the installation of this system, the micro-DFCS read the analog output directly from the
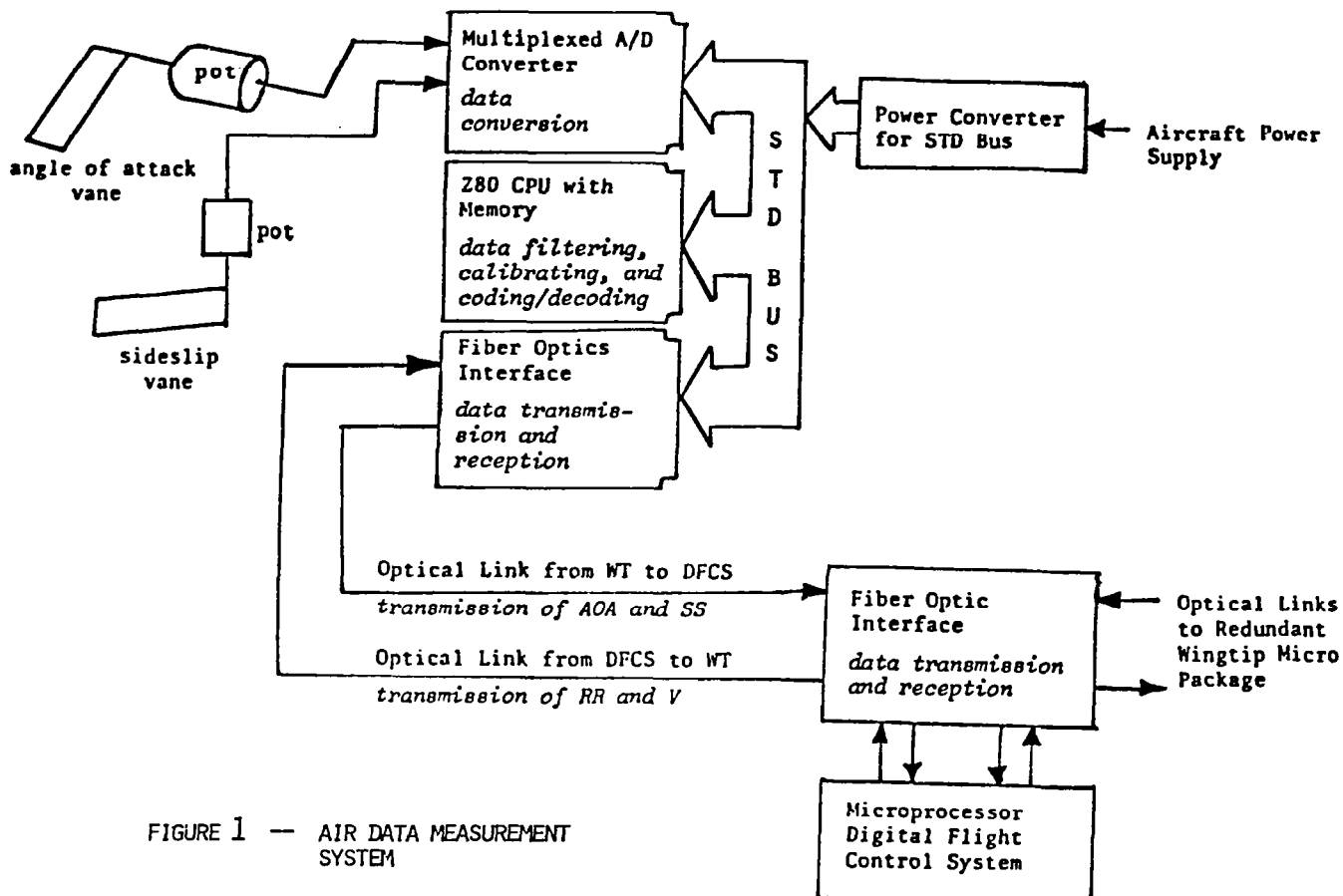
FIGURE 1 — AIR DATA MEASUREMENT
SYSTEM

air data vanes, averaging the readings from both sides to eliminate roll rate effects. No fault detection or isolation was feasible. An undetected sensor fault in a flight test program can lead to erroneous data and require costly reruns.

## HARDWARE

Figure 2 shows the VRA and the system installation. The system hardware falls into two categories — computational and communications. All hardware used to collect, calibrate, and filter data and detect errors is grouped under the computational heading; the communications category consists of the fiber optic links. The following two sections describe each component in detail.

### Computational Hardware

Wingtip Microprocessor Package (WIMP). Each WIMP unit has three cards — CPU, A/D, and fiber optics interface — mounted in a Prolog STD card cage. The STD bus is a tightly structured 56-pin bus; the small size (4.5" x 5" x 0.5") and modularity of the STD components are useful where space is limited. Mostek's MDX-CPU2 card was chosen to be the wingtip central processor. It has a 4 MHz Z80 CPU and a memory of 11K (10K PROM and 1K RAM) bytes. Data Translation's DT2742 12-bit multiplexed A/D unit was selected for data conversion. The fiber optic interface consists of an optical transmitter and

receiver (described in a later section) mounted on a Prolog Utility I/O card. The wingtip packages are powered by Power Products DC-DC converters, which transform the aircraft's 28 Vdc supply to the + 5 and ± 12 Vdc needed by the WIMPs.

Microprocessor Digital Flight Control System (micro-DFCS). The VRA's micro-DFCS required only one addition for this project — two pairs of fiber optic transmitters and receivers. The Model 3 micro-DFCS (Reference [1]) consists of 3 Multibus cards — a Monolithic Systems 8004 single board computer, an Intel iSBC 732 Analog/Digital (A/D) card, and an Intel iSBC 724 Digital/Analog (D/A) card. References [1] to [3] cover this system in depth.

### Communications Hardware

A one-way fiber optic link has at least 4 components. In addition to the optical fiber itself, a transducer is needed at each end to convert the signal from electrical form to optical form (transmitter) and back again (receiver). Special connectors are needed at each end of the fiber to attach it to the transmitter and receiver. In some cases, additional connectors are needed to fasten two fibers end to end. Figure 3 shows these components.

One-way 10 meter links are used in the system. The design's power margins allow these links to be extended to 20 meters by butting two 10 meter

MICROPROCESSOR DIGITAL
FLIGHT CONTROL SYSTEM WITH
TWO FIBER OPTIC TRANSMITTERS
AND RECEIVERS

NAVION N91566

REDUNDANT
SENSORS
AND WTMP
PACKAGE

FIBER OPTIC
CABLES

AIR DATA
SENSORS

WINGTIP MICROPROCESSOR
PACKAGE WITH
--CPU AND MEMORY
--A/D CONVERTERS
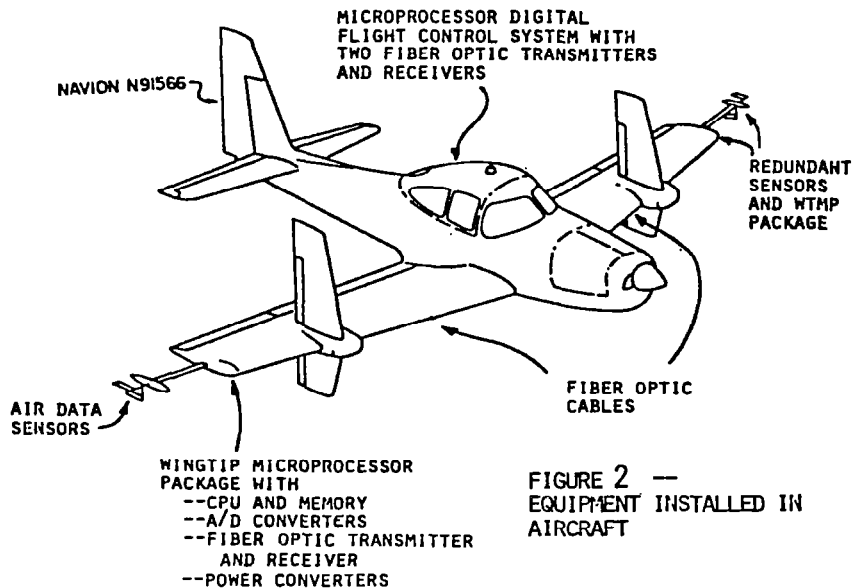--FIBER OPTIC TRANSMITTER
AND RECEIVER
--POWER CONVERTERS

FIGURE 2 —
EQUIPMENT INSTALLED IN
AIRCRAFT

fibers together with a mechanical splice, as shown in Figure 3. Power allowances also were made for the addition of couplers or duplexers at a later date.

The design procedure for an aircraft fiber optic link differs from that of a generic fiber optic link in only one respect — special consideration must be made for the harsh environment. References [4] to [7] give introductions to the design of links similar to the ones described here.

Link Components

Fiber and Cabling. The Siecor 155 multi-mode, step-index fiber was selected because it combines the advantages of all-glass fibers (low attenuation, small performance variations over wide temperature changes, resistance to harsh environments, and ease in installing connectors) with the large core diameter and high coupling efficiencies generally found only in plastic or plastic-clad fibers. This fiber's attenuation is 35 dB/km and its numerical aperture is 0.4.

In addition to the required performance parameters, this fiber has a tightly buffered, rugged cable design. Tight buffering was selected over loose buffering in spite of the higher tensile strength and slightly lower attenuation of the latter cable design because it displays much better crushing resistance and more uniform performance over wide variations in temperature [8]. With this cabling, the fiber can withstand an installation load of up to 400 N, a crush load up to 500 N/cm, and a minimum bending radius of 15 mm.

Transmitter and Receiver Modules. Optelecom's 2100 series digital transmitter/receiver set was selected for the system because it has a high attenuation margin and dynamic range (23 dB), maintains a low bit error rate (1 bit error in 10 bit transmissions at maximum attenuation), and has no coding limitations. Its 820 nm operating wavelength matches the minimum attenuation spectrum of the fiber selected as well as that of many other fibers. The bandwidth capability (5 Mb/s with RZ coding and 10 Mb/s with NRZ coding) exceeds Mil Standard 1553 requirements for the foreseeable future. The small size of the modules (2" x 1.5" x 0.65") allows their installation inside the STD bus card cages, very close to the controlling computer. Also, they are well shielded from electromagnetic interference, a must for this noisy environment.

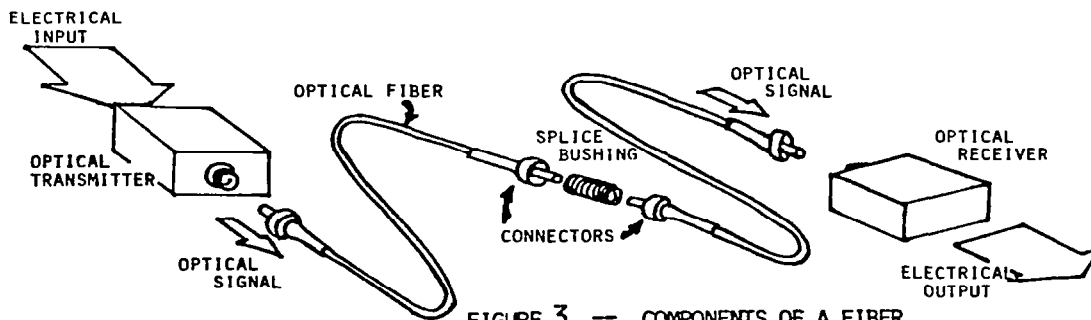Connectors. Epoxy Technology's all-metal SMA type epoxy-bond-and-polish connector was selected



ELECTRICAL
INPUT

OPTICAL FIBER

OPTICAL
SIGNAL

OPTICAL
TRANSMITTER

SPLICE
BUSHING

OPTICAL
RECEIVER

CONNECTORS

OPTICAL
SIGNAL

ELECTRICAL
OUTPUT

FIGURE 3 — COMPONENTS OF A FIBER
OPTIC LINK

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for the fiber terminations. This connector has equal performance for either fiber-to-fiber or fiber-to-T/R junctions (1.0 dB). The pull-out strength of the installed connector is 150–200 $lb/ft^2$

Installing Epoxy-bond-and-polish connectors requires skill, time and some simple tools. In addition, the connectors cannot be reused on another fiber. The non-epoxy alternatives, while generally reusable and considerably easier to install, are either more expensive or not sufficiently rugged, have higher attenuation, and require sophisticated fiber preparation tools. Therefore, the epoxy-bond-and-polish connector was chosen with the actual installation being done by Light Control Systems.

## Link Performance

The attenuation of the 10-meter fiber-connector combination is 4 dB; a spliced 20-meter link's attenuation is nearly twice this amount. Because the transmitter launches approximately 27 dBμ into the fiber and the receiver's detection threshold is 3 dBμ, there is a 20 dB attenuation margin to allow for system performance degradation due to time and temperature changes, as well as future hardware additions such as multiplexers and couplers.

## SOFTWARE

### Data Preparation

The WIMPs perform several functions before sending data to the micro-DFCS. These include (1) data acquisition, (2) scaling, (3) filtering, and (4) calibration. To save time in software development, tasks (2), (3), and (4) are programmed using the high level language Pascal/MT. Due to precise timing requirements, task (1) was coded in assembly language. A summary of these tasks follows.

Data Acquisition. Data acquisition control consists of initializing the A/D unit for the appropriate channel and reading the 12-bit integer result when the A/D board signals completion of the conversion.

Data Scaling. Because the raw data are offset integer representations of potentiometer voltages, scaling is required. First the offset or zero bias is subtracted. Then each raw integer is converted to a floating point number and multiplied by a scaling constant to convert it from a voltage to an angle.

Data Filtering. High frequency noise in the raw sensor data is removed by a simplified Kalman filter. To implement this filter, the angle of attack ($\alpha$) and sideslip angle ($\beta$) are assumed to be dynamically uncoupled, to be heavily damped, and to have a response sufficiently fast that they can be considered to be in steady state at all times. Further, the $\alpha$ and $\beta$ inputs can be modelled as first order Gauss-Markov processes. The measurements from the vanes, $z_\alpha$ and $z_\beta$, are assumed to be properly scaled, to have bias removed, and to be subject to white noise. The $\alpha$ and $\beta$ estimates are given by

$$\hat{\alpha}_K = \hat{\alpha}_{K-1} + k_\alpha(z_{\alpha_K} - \hat{\alpha}_{K-1}) \qquad [1]$$

$$\hat{\beta}_K = \hat{\beta}_{K-1} + k_\beta(z_{\beta_K} - \hat{\beta}_{K-1}) \qquad [2]$$

and k, the scalar Kalman gain, is given by

$$k = \frac{2}{1 + \left[1 + \left[\frac{2\sigma_v}{2\sigma_w}\right]^2\right]^{1/2}} \qquad [3]$$

where $\sigma_v$ and $\sigma_w$ are covariances of the measurement noise and the process noise, respectively. This filter is derived in reference [9].

Data Calibration. The local $\alpha$ and $\beta$ at the wingtips are coupled by wingtip vorticity. In addition, roll rate (p) causes a local $\alpha$ increment, pb/2V (where b is the spanwise location of the $\alpha$ vane), that is not measured at the aircraft's center of gravity. Both of these effects must be eliminated by a transformation of the form

$$\begin{bmatrix} \alpha_c \\ \beta_c \end{bmatrix} = \begin{bmatrix} C_{11} & \pm C_{12} \\ \pm C_{21} & C_{22} \end{bmatrix} \begin{bmatrix} \hat{\alpha} \\ \hat{\beta} \end{bmatrix}_K + \begin{bmatrix} \pm \dfrac{p_K b}{2V_K} \\ 0 \end{bmatrix} \qquad [4]$$

Effects of yaw rate on sideslip angle are negligible and are not included in this transformation. The vorticity correction coefficients $C_{ij}$ are velocity dependent and must be recomputed during every data processing cycle. The signs of these transformation coefficients depend on which wingtip is under consideration.

### Data Communications Structure

In this system, the two microprocessors in the wingtips are loosely coupled to the micro-DFCS, which is the executive processor of the system. The traffic management algorithm chosen for data exchange between the microprocessors uses a modified polling scheme. The micro-DFCS interrupts the wingtip microprocessors whenever angle-of-attack or sideslip data are needed and whenever new roll rate and velocity data are available. The micro-DFCS sends the WIMP being polled a 3-bit variable name (001 for sideslip, 002 for roll rate, etc.) as soon as its interrupt is answered, so the WIMP knows which value to send or receive. Each transmission is ended with a parity bit for error detection. Figure 4 shows the message format.

The wingtip microprocessors cannot interrupt the micro-DFCS, because uncontrolled delays in some flight control routines might be undesirable. Perhaps equally important, a "babbling" failure of a wingtip unit cannot cripple the entire flight
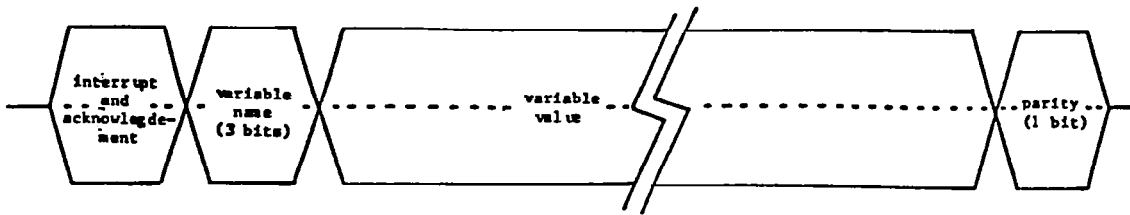
FIGURE 4 — MESSAGE FORMAT

control system by continuous uncontrolled interrupts. This bus protocol minimizes the data communications overhead for all processors, the timing sensitivity, and the propagation of wingtip microprocessor problems to the micro-DFCS.

Manchester Bi-Phase code is used to transmit data; this code is also known as self-clocking return-to-zero (RZ) code. The beginning of each bit interval is marked by a transition. If the bit is a one, a second transition will occur in the middle of the interval; for a zero bit, the signal will remain at the same level throughout the interval (Figure 5). This code requires twice the bandwidth of more commonly used non-return-to-zero (NRZ) code schemes, but it eliminates many of their timing problems and lengthens transmitter life [10].
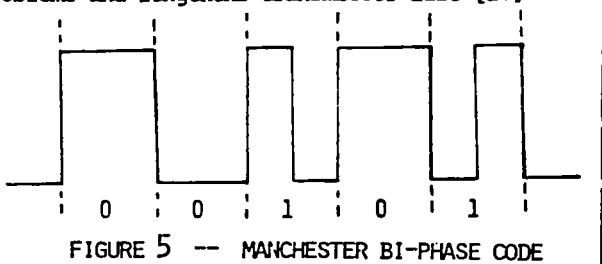


FIGURE 5 — MANCHESTER BI-PHASE CODE

All coding for data transmission is done by software, in order to maintain flexibility, even though this limits the maximum speed to an order of magnitude slower than the controlling microprocessor. The baud rate currently being used is 31000 bits per second.

Redundancy Management

The dual redundancy of the system cannot be translated into fault tolerance without adequate software. Redundancy management requires fault detection and recovery. Fault detection is the driving portion of fault tolerance, since recovery procedures will not be applied if the associated fault is not detected. It is important to detect a fault even if no recovery is possible in a flight test, since much time and money can be saved by aborting a test which would otherwise result in useless data. Of course, the degree of detection and recovery possible depends on the area and type of failure occurring.

Possible breakdowns in this system may be classified by the area in which they occur [data preparation or data communications] and their type [hard (permanent) or soft (temporary)]. Figure 6 shows some samples of faults anticipated in each category, as well as the detection method used and whether recovery is possible.

The possibility of transmission errors is addressed during the transmission itself; if the data pass these tests, their accuracy is examined. Faults in data communications are easiest to detect, since they generally result in incomplete, incoherent, or inconsistent transmissions. Incomplete or, in many cases, incoherent transmissions can be detected when a bit transition fails to occur in a specified time interval. Incoherent transmissions that meet the transition timing requirements will be caught by the parity check at the end of the transmission. Even if neither of these tests catches an error, the faulty data will be caught in the data preparation screening. If a data communications flaw is detected, the data from the processor in question are discarded for the current cycle. In the unlikely event that data from both WIMPs are improperly transmitted in the same cycle, the micro-DFCS must repoll one WIMP in order to obtain some data for the control system.

Detecting a fault in the data preparation is more complicated. In this system, a Sequential Probability Ratio Test (SPRT) (References [11] and [12]) will be used to evaluate the difference between the results from each WIMP. The micro-DFCS assumes that both sensors are operative as long as the difference between the two sensors has a mean of zero. If this mean shifts away from zero, a bias failure in one of the sensors has occurred. Unfortunately, with only dual redundancy it is very difficult — if not impossible — to isolate such a failure to one WIMP. A third opinion is needed. Use of analytically derived aircraft acceleration limits is being considered for the third opinion; this may be useful in isolating sudden sensor package failures.

Only three fault recovery options are available in this system: (1) ignoring the output of the faulty processor, (2) repeating the reading in question, and (3) resetting one or both units. The first two procedures can be used only when a fault can be attributed to one WIMP, usually the case for transmission errors. Alternative (1) is used most often. Any error detected in transmission is assumed to be temporary; the error is recorded and bypassed until repeated occurrences justify removing the affected WIMP from the loop entirely. Transmission faults from both WIMPs in the same cycle require alternative (2), repetition. The micro-DFCS cannot repeat requests indefinitely, however, and will quickly resort to (3) (resetting the system) if data cannot be obtained on a second try. Resetting one or both WIMPs may also be done when a data preparation fault is detected. This is done in case the fault is due to a processor having

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| ERROR TYPE | | POSSIBLE ERRORS | DETECTION | RECOVERY |
|---|---|---|---|---|
| DATA COMMUNI- CATIONS | SOFT | -Bit error<br>-Power supply transient | -Failure to answer poll<br>-Failure to finish transmission<br>-Incoherent transmission | -Discard data sample from affect WTMP<br>-Request retransmission of data in question |
| | HARD | -Failed transmitter or receiver<br>-Broken fiber<br>-Local power failure | | -Stop requesting data from affected WTMP<br>-Reset affected WTMP |
| DATA PREPARA- TION | SOFT | -Temporary A/D failure<br>-Temporary CPU failure<br>-Temporary memory failure | -Comparison of both WTMP computations | -Attempt to isolate failure to one WTMP<br>-Reset one WTMP if failure isolation is possible<br>-Reset entire system if failure isolation is not possible |
| | HARD | -Permanent A/D failure<br>-Permanent CPU failure<br>-Permanent memory failure | | |

FIGURE 6 — ERROR DETECTION AND RECOVERY

been "glitched" into an incorrect state that could be corrected by reinitialization. A total reset results in a significant delay in data availability, so the pilot is warned before this action takes place.

### SYSTEM TESTING

Testing of the system has begun and will be completed in the near future. Extensive ground testing has verified that the hardware and software operate as designed in a laboratory environment. Only in flight tests can the system's design be completely evaluated, however.

Flight testing of the system has been divided into two phases: (1) hardware evaluation and (2) total system evaluation. The primary goal of the first phase is to verify that all the hardware performs satisfactorily in flight. These tests are being done with a minimum of software so that any hardware faults can be separated easily from software bugs. Of course, the communications hardware cannot be tested adequately without the data communications software, so the data transfer techniques are being tested simultaneously. A secondary task scheduled in this part of the testing is collecting some data to check the calibration coefficients that will be used in the system.

A first flight, checking the data transmission between a single WTMP and the micro-DFCS, has been completed with satisfactory results. During this flight, the outside air temperature was -13° C. In over 2000 data transmissions in this flight, no transmission errors occurred.

The second phase of the flight testing, total system evaluation, will focus primarily on evaluating the data filtering and calibration software as well as the system's fault tolerance.

### CONCLUSION

A dual-redundant air data measurement system incorporating distributed microprocessors and fiber optic data transfer to a central processor has been designed and fabricated, and testing has begun. The system is installed in a flight test aircraft which provides a realistic environment for experimentation, and it has demonstrated satisfactory operation in a preliminary flight test. The technology under study shows considerable promise for enhancing the reliability and performance of future flight control systems.

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# DATA ACQUISITION FOR STALL/SPIN FLIGHT RESEARCH

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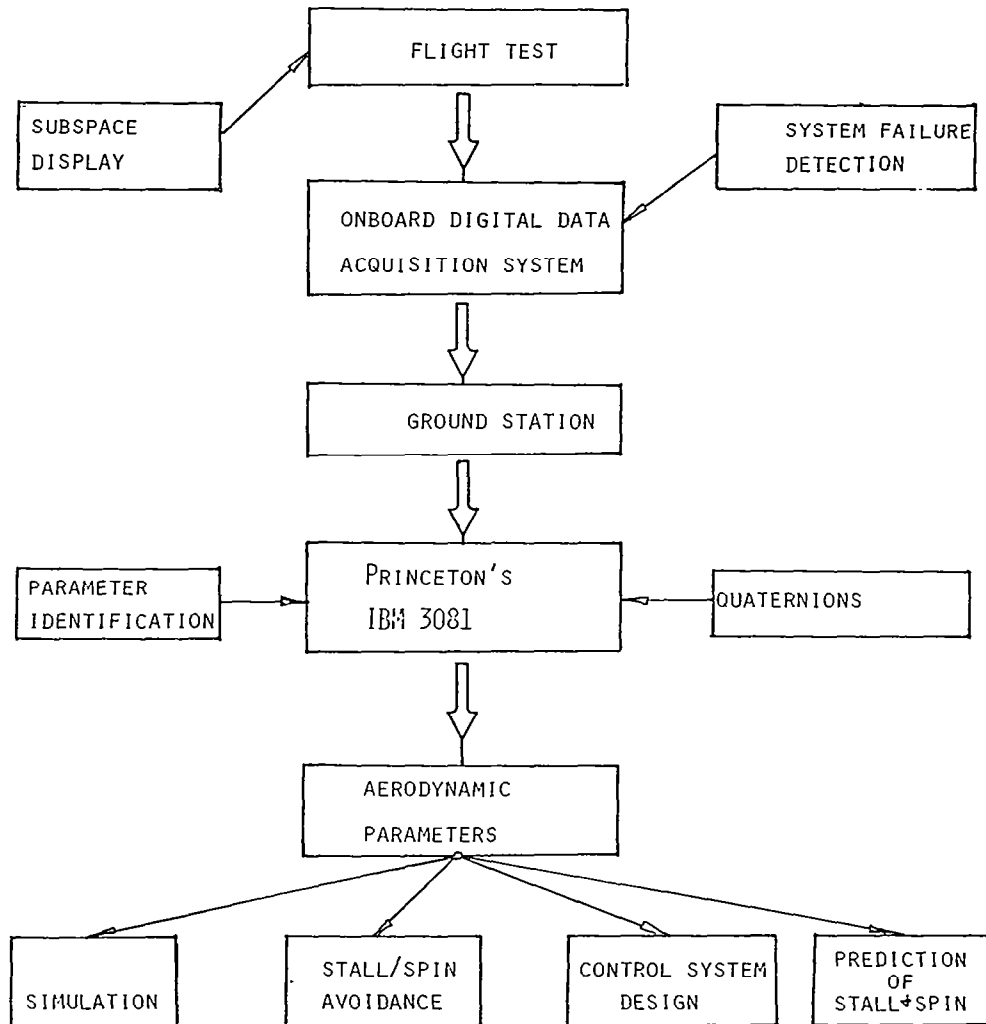Princeton, New Jersey

# DATA ACQUISITION FOR STALL/SPIN FLIGHT RESEARCH

A special purpose digital data acquisition system is built for stall/spin flight research. A Schweizer 2-32 sailplane is used as the test vehicle. Computer hardware and its architecture are described. Concepts of system failure detection are considered in the design. Special instrumentation developed for the high angle of attack flight is presented. A representative flight time history of a maneuver also is shown. The flight data will be used for the identification of aerodynamic parameters.

o OBJECTIVE

o CIBOLA 2-32 SAILPLANE

o COMPUTER ARCHITECTURE

o SPECIAL INSTRUMENTATION

o SYSTEM FAILURE DETECTION

o FLIGHT TEST DESIGN

o CONCLUSION

## OBJECTIVE

The data acquisition system is designed to be portable.
The computer based data collection system is also used to
monitor the sensor system "health". The collected flight data
is transferred to a ground based computer (IBM 3081) and the
aerodynamic parameters are estimated. Aerodynamic parameters
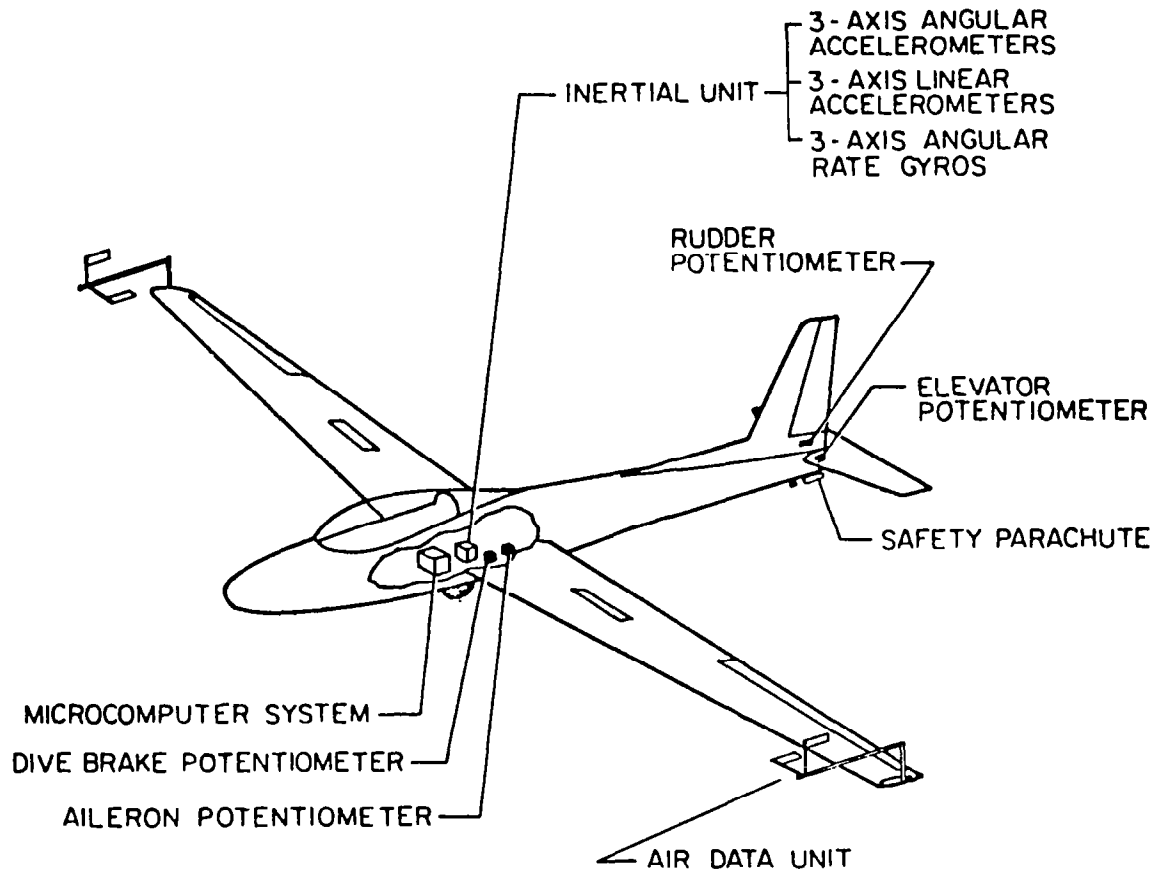can be used in several areas such as simulation, control system
design, etc.

```
                        ┌─────────────────┐
                        │   FLIGHT TEST   │
                        └─────────────────┘
                                 ⇓
┌──────────────┐        ┌─────────────────┐        ┌─────────────────┐
│ SUBSPACE     │────╲   │ ONBOARD DIGITAL │        │ SYSTEM FAILURE  │
│ DISPLAY      │        │ DATA ACQUISITION│◄───╲   │ DETECTION       │
└──────────────┘        │ SYSTEM          │        └─────────────────┘
                        └─────────────────┘
                                 ⇓
                        ┌─────────────────┐
                        │ GROUND STATION  │
                        └─────────────────┘
                                 ⇓
┌──────────────┐        ┌─────────────────┐        ┌─────────────────┐
│ PARAMETER    │───►    │  PRINCETON'S    │◄───    │ QUATERNIONS     │
│ IDENTIFICATION│       │  IBM 3081       │        └─────────────────┘
└──────────────┘        └─────────────────┘
                                 ⇓
                        ┌─────────────────┐
                        │ AERODYNAMIC     │
                        │ PARAMETERS      │
                        └─────────────────┘
```

| SIMULATION | STALL/SPIN AVOIDANCE | CONTROL SYSTEM DESIGN | PREDICTION OF STALL◊SPIN |
|---|---|---|---|

# ELEMENTS OF PARAMETER IDENTIFICATION

An instrumentation package, a data acquisition system, a flight test procedure, and identification algorithms are crucial to parameter identification. Once a set of parameters have been identified, the aerodynamic model should be validated.
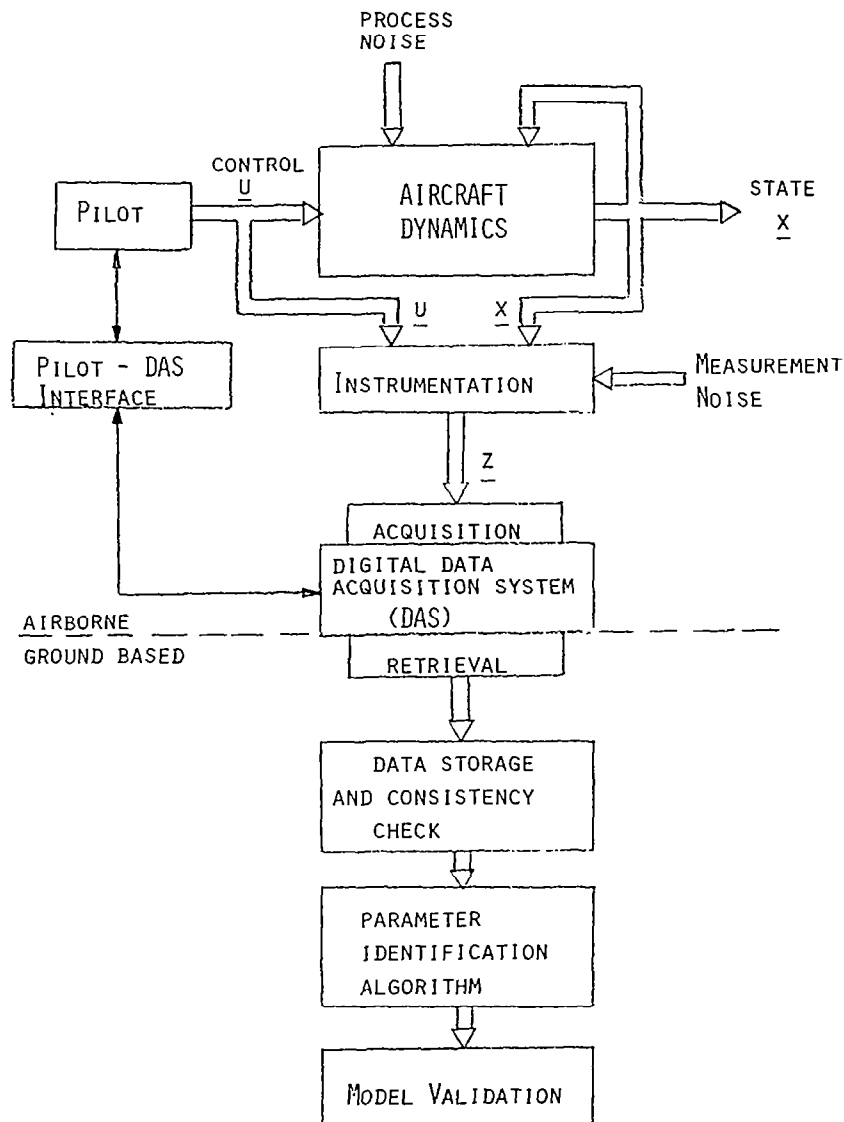
## CIBOLA 2-32 SAILPLANE

The two-seat Schweizer 2-32 (Cibola) sailplane is used as the test vehicle.  The inertial measurement unit (IMU) and the microcomputer system are located behind the second seat. The air data units (ADU) are mounted at the wing tips.

INERTIAL UNIT
— 3-AXIS ANGULAR ACCELEROMETERS
— 3-AXIS LINEAR ACCELEROMETERS
— 3-AXIS ANGULAR RATE GYROS

RUDDER POTENTIOMETER

ELEVATOR POTENTIOMETER

SAFETY PARACHUTE

MICROCOMPUTER SYSTEM

DIVE BRAKE POTENTIOMETER

AILERON POTENTIOMETER

AIR DATA UNIT

## MICRO-MAP HARDWARE

The data acquisition system is referred to as Micro-MAP (Microprocessor-Based system for the Measurement of Aerodynamic Parameters). The inertial measurement unit and the computer system are two important subsystems. The inertial measurement unit is designed to function as a junction box to provide modularity and portability. The computer system provides the automatic data acquisition and sensor monitoring capability. The inertial measurement unit weighs 24 lbs, the computer system weights 20 lbs, and the batteries and power supply components weigh 65 lbs. The total power of the Micro-MAP is 150 watts.
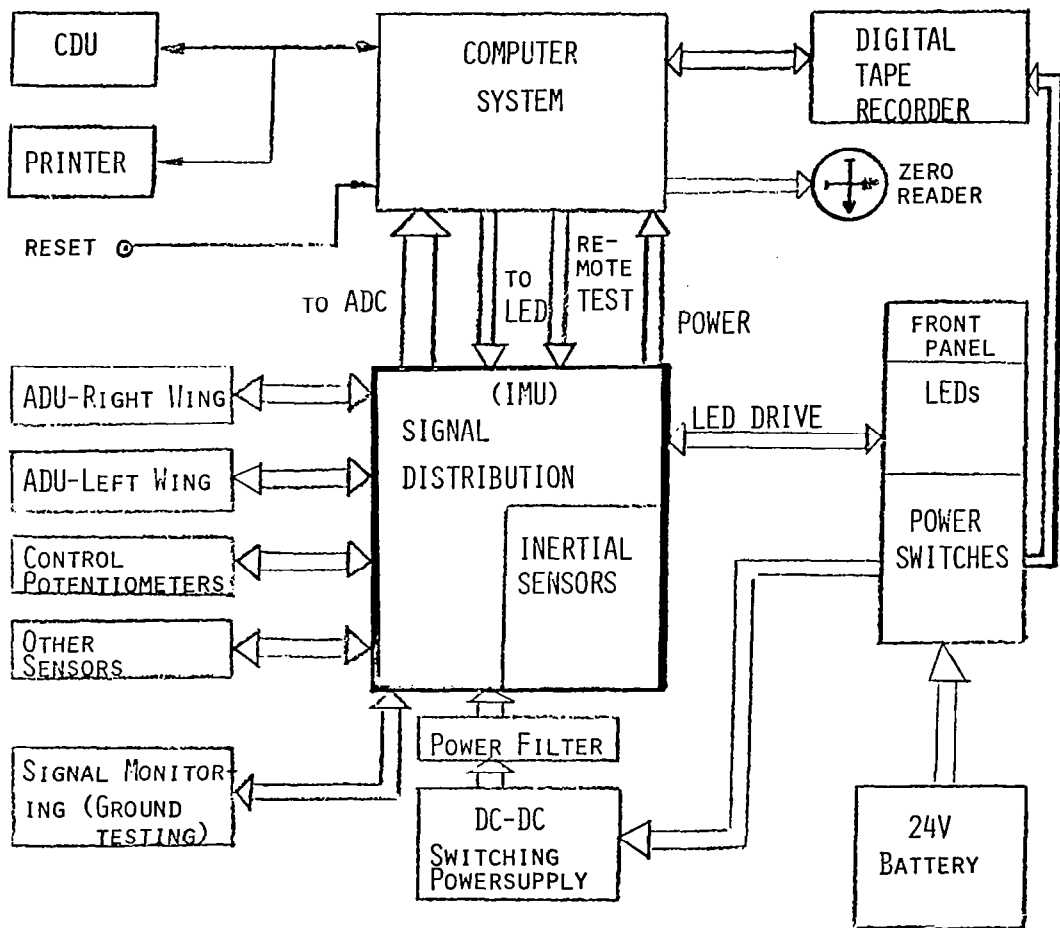
## COMPUTER ARCHITECTURE

Two Multibus<sup>TM</sup> compatible microcomputers are programmed
to operate as multiprocessors. The CPU#0 accomplishes the data
sampling and digitizing using the analog-to-digital converter
board. Sensor system monitoring is also performed by the CPU#0.
The data storage and retrieval are performed by CPU#1 which is
dedicated for tape control. Sensor outputs are filtered before
sampling. The computers require regulated +28 V, +/-12 V and
+5 V.
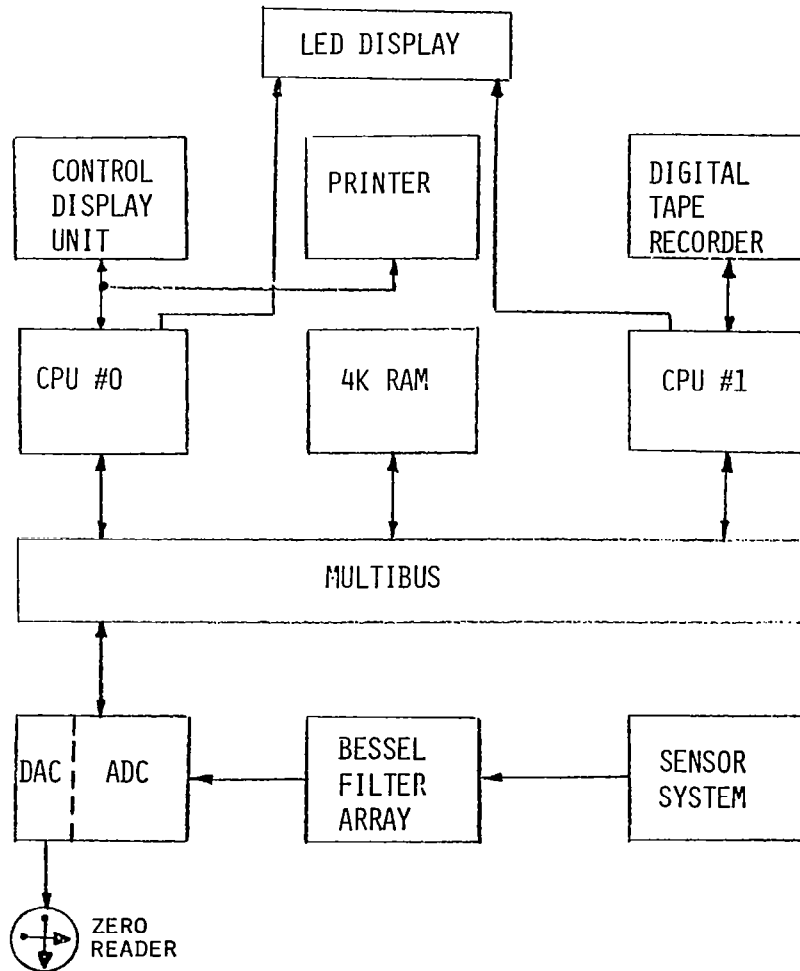
## INERTIAL COMPONENTS

The inertial sensors (3 linear accelerometers, 3 angular accelerometers, and 3 angular rate gyros) are rigidly mounted in an aluminum box and mounted near the aircraft's center of gravity. The inertial measurement unit has a dimension of 10" x 10" x 9".
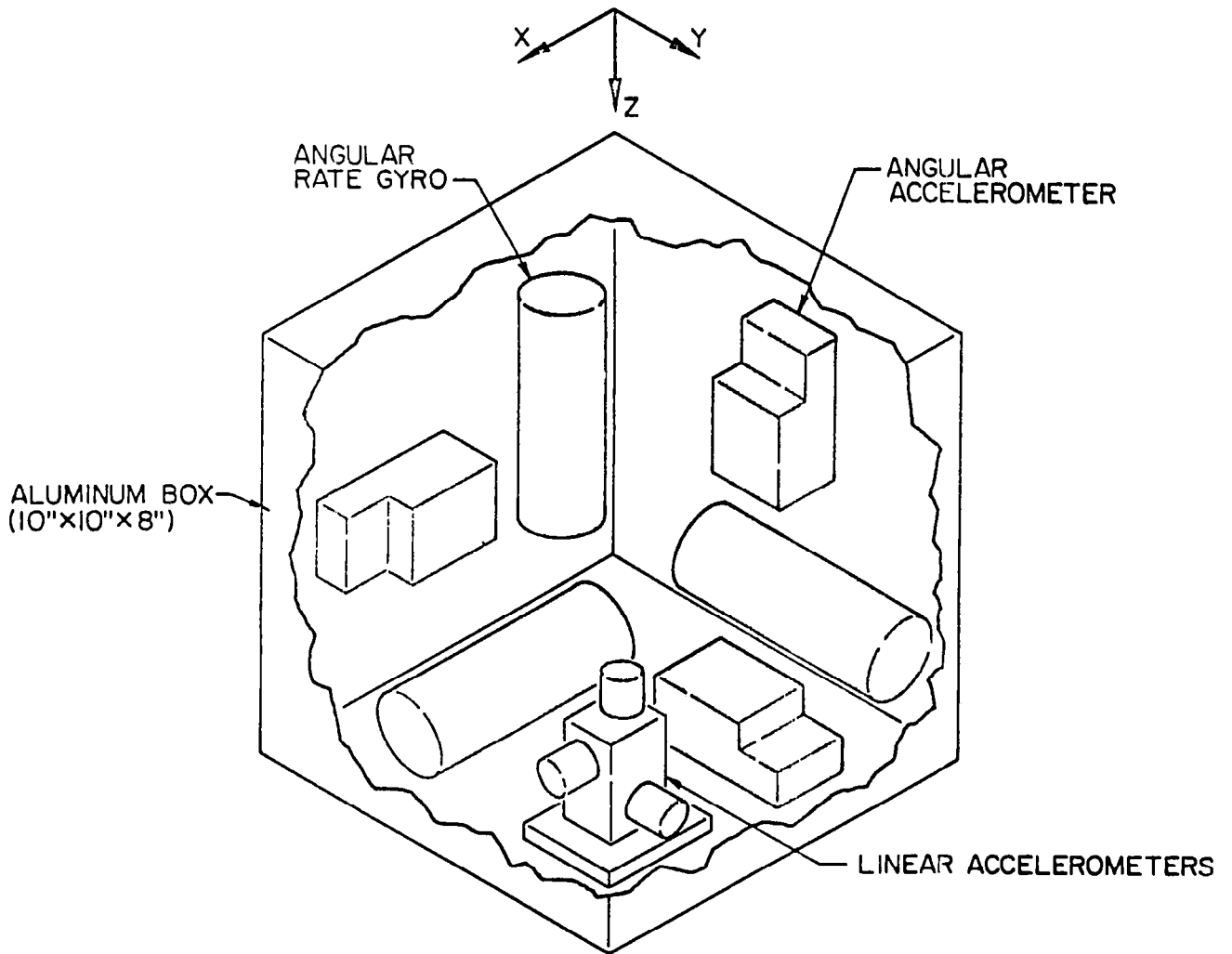
## AIR DATA UNIT

The total pressure is measured using a Kiel probe. Two rectangular vanes provide angle of attack and sideslip measurements. Two air data units are mounted on the wing tips. Flow interference is reduced by positioning the sensors upstream of the leading edge.

STATIC PRESSURE PORTS

α - VANE

KIEL TUBE

PITOT TUBE

VENT HOLES

α - VANE POTENTIOMETER

BOOM ATTACHED TO WING

β - VANE
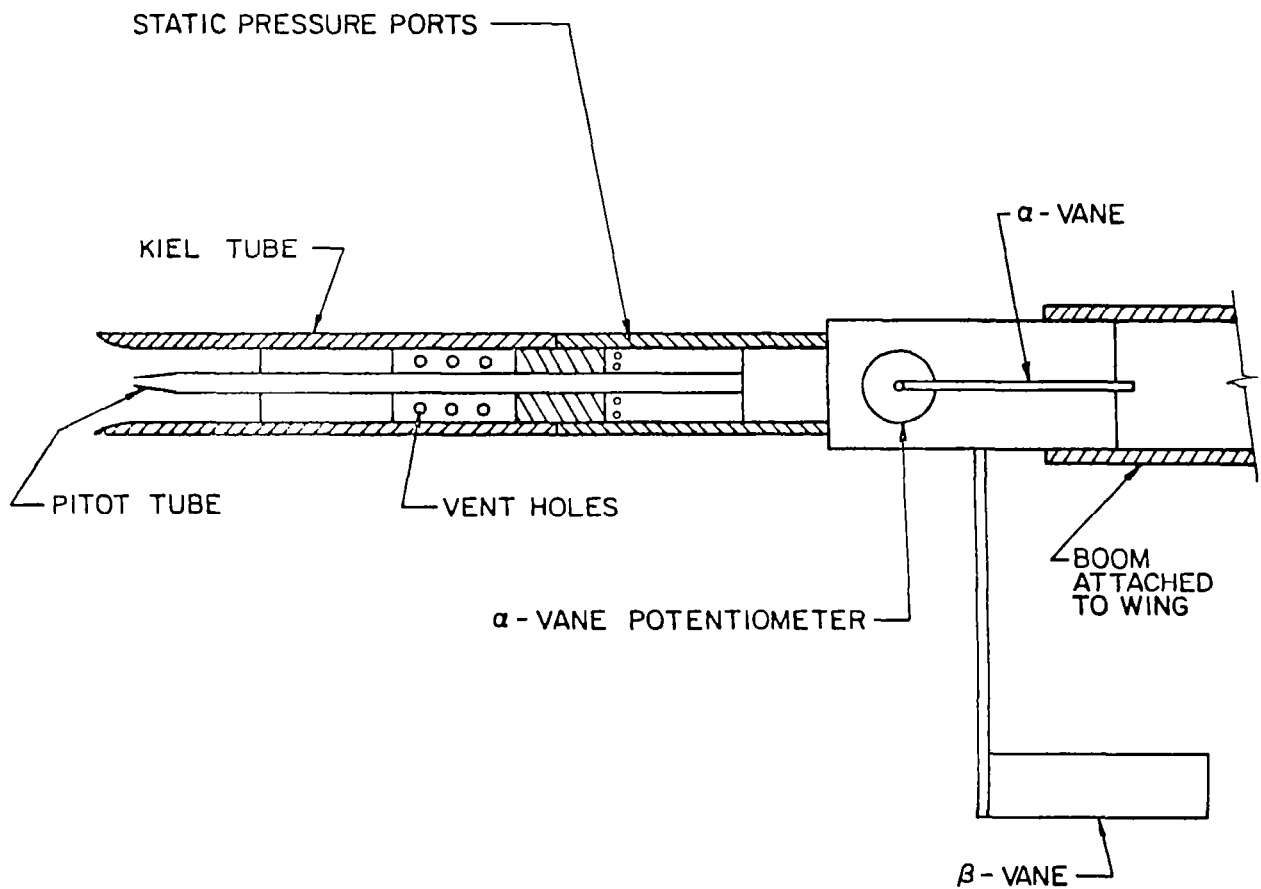
# WIND TUNNEL TEST

The wind tunnel test performed on the pitot-static
system (with Kiel probe) shows the reduced sensitivity of
total pressure measured to large flow angles.  The measurement
is seen to be flat to a total angle of 60°.

TOTAL HEAD (PSF GAUGE)
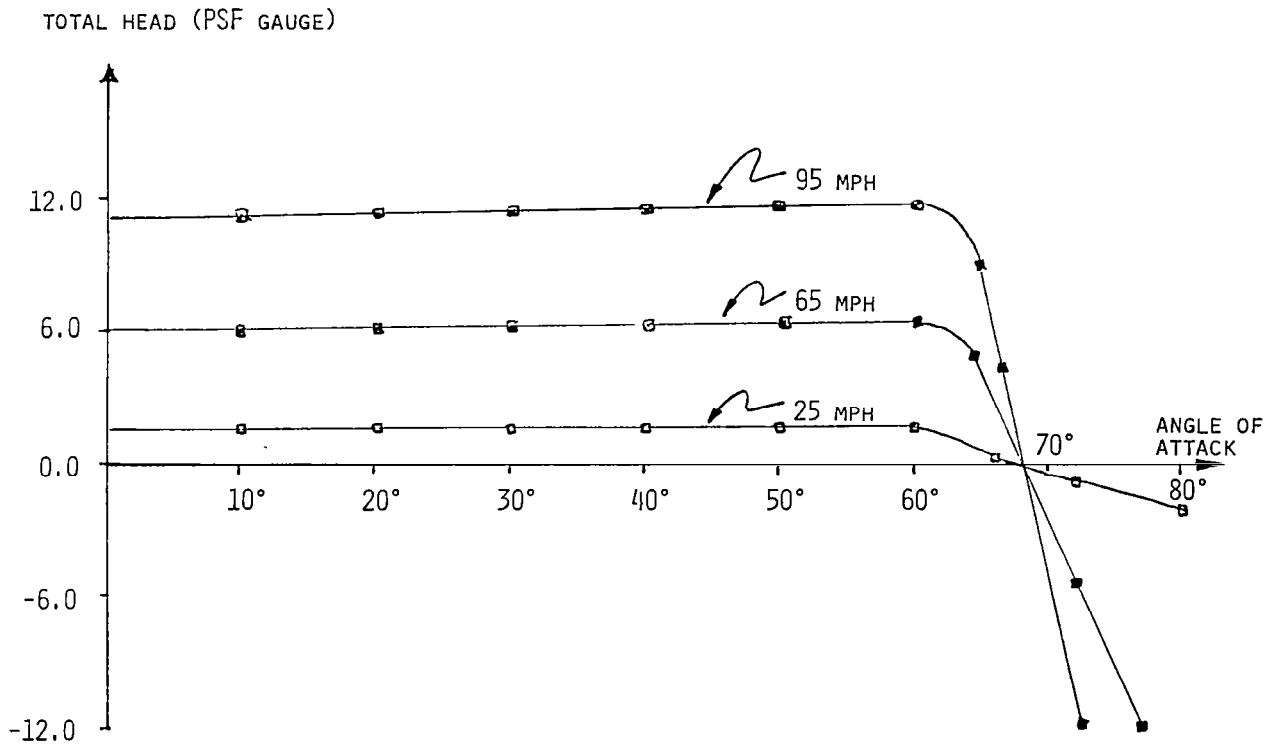
## SOURCES OF FAILURE OF MICRO-MAP

The Micro-MAP could fail to operate under various conditions. The sources of failure can be categorized into six groups. Computer operation is considered mandatory for detection of the remaining four failure types. Eight light-emitting diodes located in the cockpit are programmed to display the Micro-MAP status.
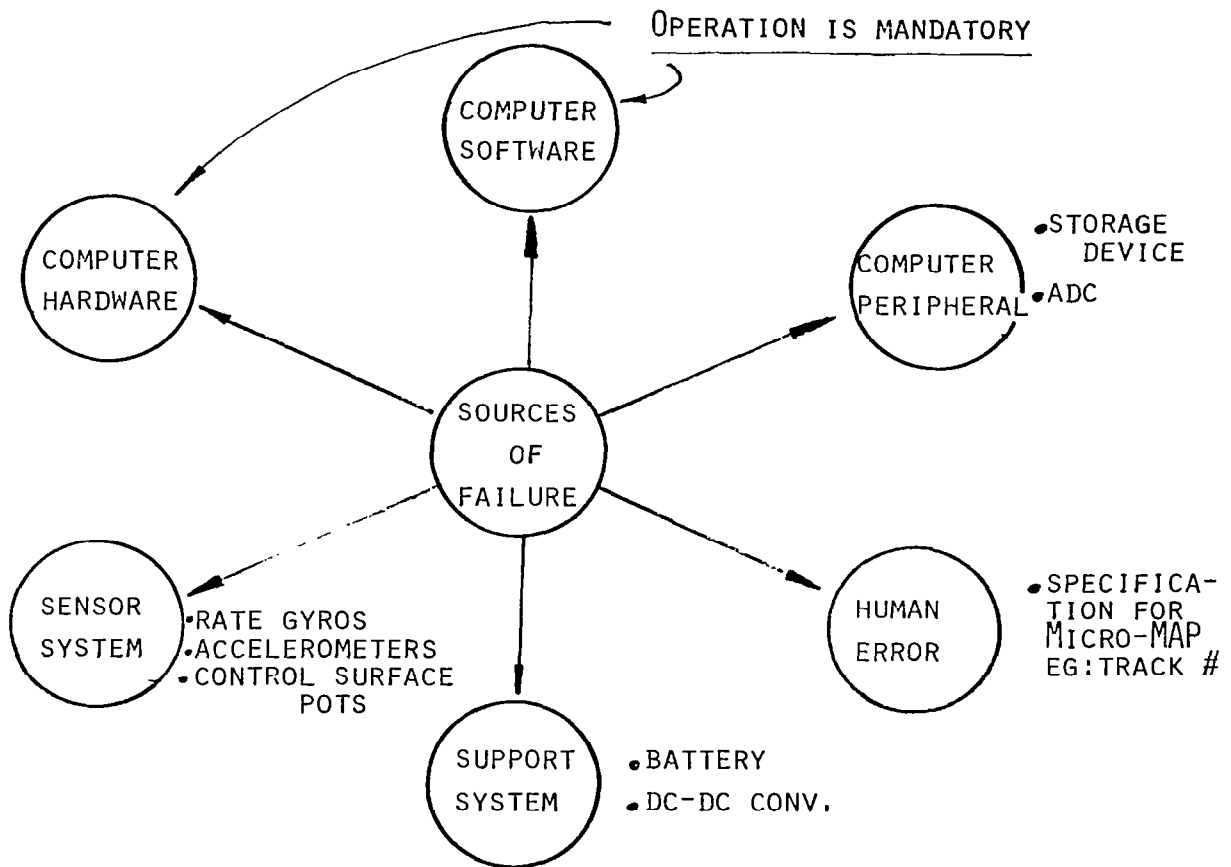
## PARAMETER IDENTIFICATION METHODS

Among the existing identification methods, Estimation-Before-Modeling technique is suitable for high angle of attack parameter identification. The complex modeling and aircraft state estimation problems are separated. In addition, it identifies a single model of each aerodynamic coefficient for all maneuvers rather than one for each maneuver, as is usual with other methods.

EXTENSIVELY USED METHODS
- MAXIMUM LIKELIHOOD
- EXTENDED KALMAN FILTER
- ESTIMATION BEFORE MODELING

STEP 1

FLIGHT DATA → OPTIMAL ESTIMATION ALGORITHM → TIME HISTORIES OF STATES, FORCE AND MOMENT COEFFICIENTS

TIME DOMAIN

STATE DOMAIN

STEP 2

STATE MODEL IDENTIFICATION

AERODYNAMIC MODEL
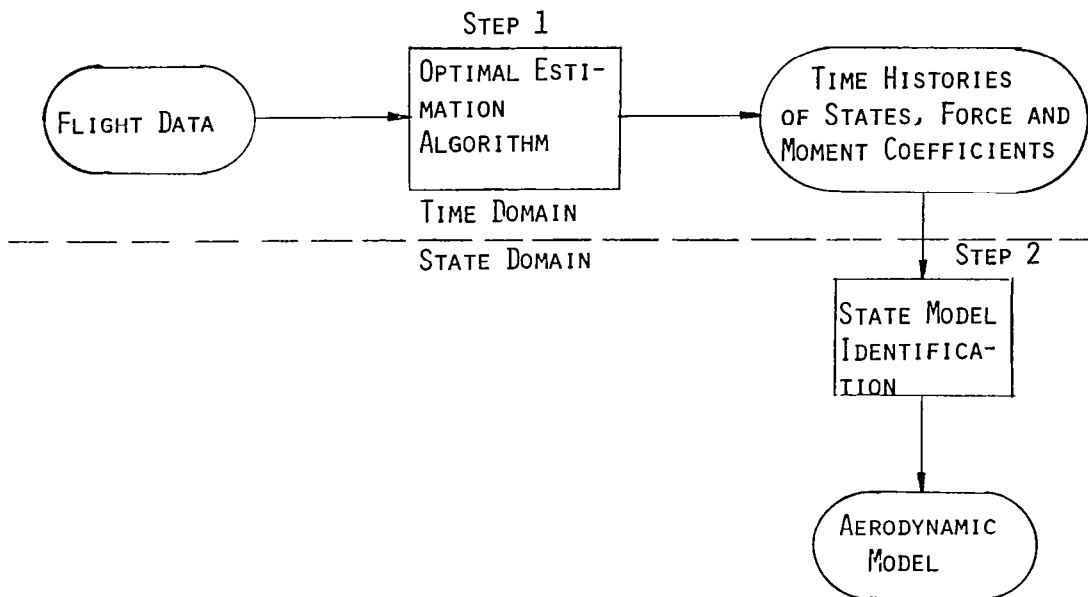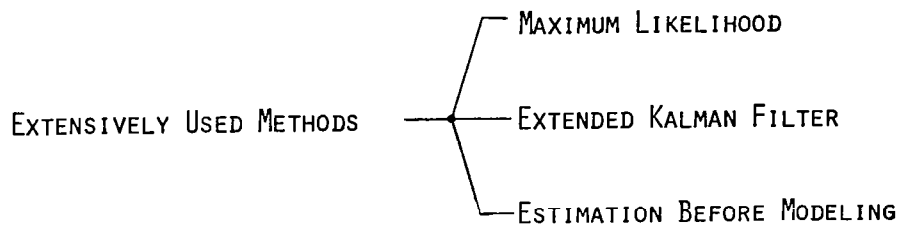
## FLIGHT TEST DESIGN

Sufficient flight test data in each subspace is essential for the regression analysis. The flight testing is performed systematically using the Micro-MAP by displaying to the pilot the required angle of attack and sideslip corresponding to a subspace.

OBJECTIVE: TO IMPROVE THE DISTRIBUTION OF FLIGHT TEST DATA
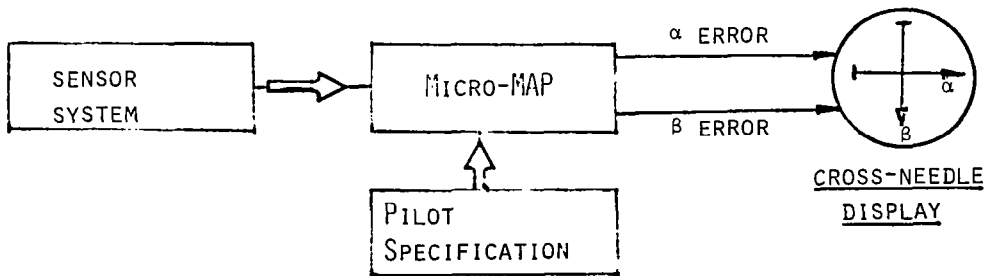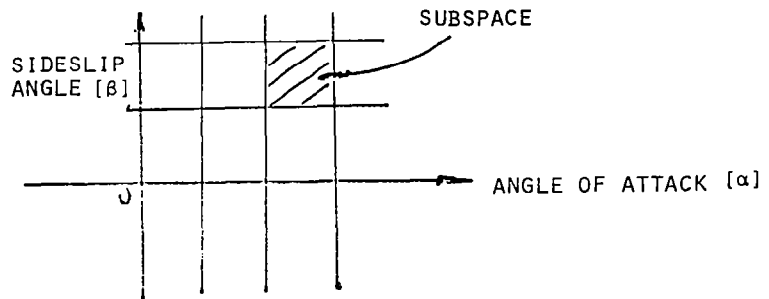
## FLIGHT TEST RESULTS - CONTROL INPUTS

The time history of the control inputs which generates dynamic motion about all three axes is presented. The maneuver consists of 7 s of trim data and about 30 s of dynamic data. The trim data will be used to compute the initial condition required by the estimation algorithm. The dynamic part of the flight data will be used in the regression analysis, by which the aerodynamic parameters will be computed.
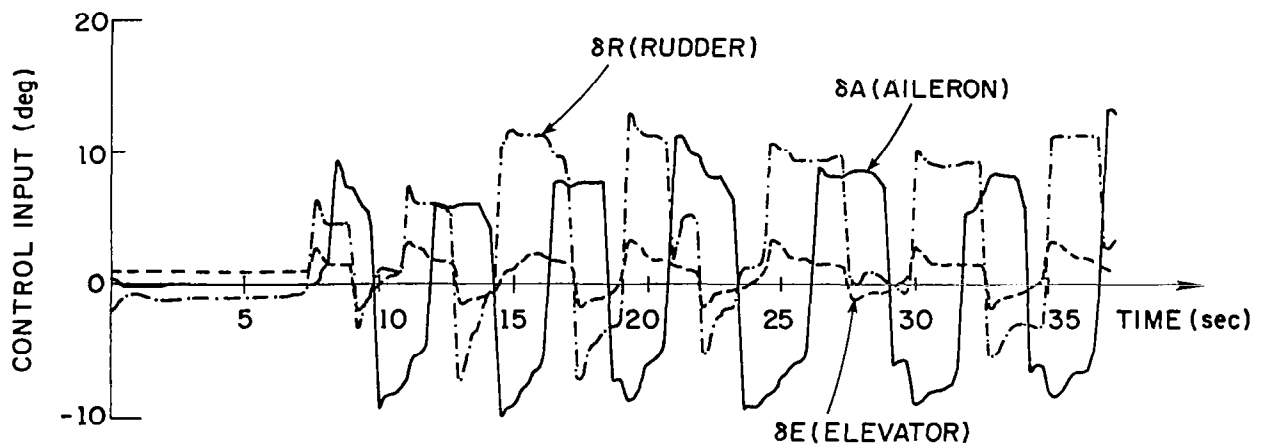
# FLIGHT TEST RESULTS - LINEAR ACCELERATION

The time history of the three components of the linear acceleration corresponding to the control inputs is shown in this figure. The acceleration components in the X and Y directions are relatively small, but the variation is important for regression analysis.

The elevator primarily controls the pitching moment acting on the aircraft. The linear acceleration in the Z direction is controlled by the resulting change in the angle of attack. However, in the figure, the switching of the elevator angle causes a noticeable jump in the linear acceleration, which can be attributed to the change of total lift due to the change in the elevator angle.
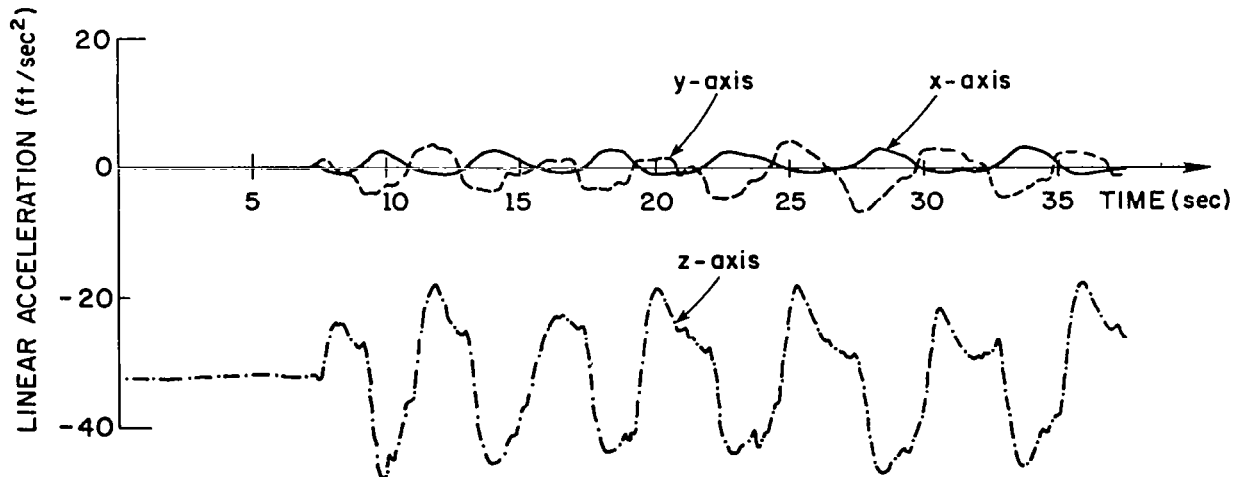
CONCLUSIONS

        The data acquisition system has been designed and
flight tested.  It is self-contained and portable.  The instru-
mentation and the identification algorithms have been designed
to accommodate high angle of attack flight domain.  The on-board
computers are programmed to monitor the sensor systems and to
improve the flight test effectiveness.  The Estimation-Before-
Modeling technique has been chosen as the parameter identifi-
cation procedure.

- DATA ACQUISITION SYSTEM HAS BEEN DESIGNED AND FLIGHT TESTED

- SIMPLE FAILURE DETECTION TECHNIQUES HAVE BEEN IMPLEMENTED

- USING INFLIGHT COMPUTATIONAL POWER, FLIGHT TESTING IS MADE
  SYSTEMATIC

- PARAMETER IDENTIFICATION ALGORITHMS HAVE BEEN IMPLEMENTED

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15. Supplementary Notes

16. Abstract

This report summarizes the research conducted during 1982 under the NASA-sponsored Joint University Program for Air Transportation Research. This material was presented at a meeting held at NASA Langley Research Center, December 10, 1982. The Joint University Program is a coordinated set of three grants sponsored by NASA Langley Research Center, one each with the Massachusetts Institute of Technology, Ohio University, and Princeton University. Research topics include navigation; guidance, control and display concepts; and hardware, with special emphasis on applications to general aviation aircraft. Completed works and status reports are presented. Also included are annotated bibliographies of all published research sponsored on these grants since 1972.

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