TM 7001

TECHNICAL REPORT CR-151230

FEASIBILITY STUDY OF AUTOMATIC CONTROL OF CREW COMFORT IN THE SHUTTLE EXTRAVEHICULAR MOBILITY UNIT (EMU)

Job Order 81-107

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Prepared By

Lockheed Electronics Company, Inc.
Aerospace Systems Division
Houston, Texas

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For

CREW SYSTEMS DIVISION

National Aeronautics and Space Administration
LYNDON B. JOHNSON SPACE CENTER
Houston, Texas
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LEC 9980

TM 7001

TECHNICAL REPORT

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PREPARED BY

David W. Cook Jr
D. W. Cook

APPROVED BY

H. T. Crenshaw, Supervisor
Applied Physics Section

Reicks
W. J. Reicks, Manager
Applied Mechanics Department

Prepared By
Lockheed Electronics Company, Inc.
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1. INTRODUCTION

During the Apollo project, crew comfort in the Apollo Extravehicular Mobility Unit (EMU) was maintained by manual manipulation of a valve that controlled the inlet coolant temperature to the liquid cooled garment (LCG). Four inlet temperature selections were possible ranging approximately from 45°F to 80°F. During Skylab, similar comfort control was achieved by manually operating a valve which varied LCG coolant flow rate.

The Shuttle EMU design proposal includes an 11-position manual valve to vary inlet coolant temperature similar to the method used in Apollo. Eleven inlet temperatures would be available for selection vs. the four previously available.

Apollo experience indicates that some training is necessary to enhance the crewman's comfort and optimize his ability to carry a workload. Several tendencies were noted during lunar and Skylab extravehicular activities (EVA's):

a. Some crewmen precooled themselves in anticipation of a high activity level and left the valve in the valve position selected prior to the activity. A high level of training is needed for such anticipation.

b. Some crewmen tended to work at rates that were conducive to their comfort at some intermediate cooling level. They would slow down or stop and rest if they became too hot, or they would speed up or hurry to the next activity if they were too cool.

c. At times, preoccupation with a task would cause a crewman to forget comfort until excessive sweating or fatigue became imminent, and ground controllers would suggest valve changes.

It was proposed that the manual control valve be replaced with an automatic one as a product improvement item for the Shuttle program. The automatic valve proposed would sense the normally measured parameters of LCG inlet coolant temperature and LCG coolant inlet and outlet temperature difference (LCG ΔT) for use in controlling comfort. It was further proposed that if computer simulations gave encouraging results, that tests would be run on Apollo hardware in which the controller logic was simulated by real-time calculations.

LEC/ASD was tasked with determining the feasibility of such a controller using Program J196 on the 1110 computer and to develop suggested control logic for testing. This memorandum contains the results of that effort.

This concludes the requirements outlined by Action Item 46, Project 3030. The study was conducted by LEC/ASD, Dept. 641-11.

2. DISCUSSION

2.1 CONTROLLER LOGIC

2.1.1 GENERAL

Using Program J196, the 41-node man program (ref. 1), a map of comfort can be plotted at steady state. Heat stored at steady state can be calculated for a grid of metabolic rates and inlet coolant temperatures at a given inlet gas dry bulb temperature, dewpoint temperature, and flow rate, and at a given suit heat leak. LCG coolant temperature difference (LCG ΔT) as calculated at steady state by the program can be plotted vs. metabolic rate for constant inlet coolant temperatures. At each plotted point, the heat stored at steady state can be noted. When the grid is completed, comfort boundaries can be interpolated between the heat storage value as follows:

$$\text{Stored heat at comfort (Btu)} = \frac{\text{Metabolic rate (Btu/hr)} - 278 \pm 65}{13.2}$$

A series of these comfort maps have been plotted. An example of such a study is found in reference 2. An example of this type of plot is shown in figure 1.

From plots such as figure 1, a relationship between inlet coolant temperature and LCG ΔT at steady-state comfort is established (figure 2). It was established by averaging together results from several comfort curves such as in figure 1 and modifying them to get better results while developing the controller logic.

To develop logic for this controller, however, some transient data was needed in order to input to the controller how much variation in LCG ΔT was due to previous inlet temperature adjustments and how much was due to changes in the activity level of the crewman (metabolic rate). Therefore, a controller was simulated on the 41-node man program which adjusted inlet LCG temperature by the heat storage of the body. This would be the ideal controller, but the hardware is not practical. Changes in ΔT vs. changes in inlet temperature were determined as the simulated man remained at perfect comfort while being stepped from one metabolic rate to another. These points were then plotted and an average curve drawn through the points (fig. 3). This curve represents the expected changes in ΔT for every change in inlet temperature if the controller is perfectly tracking comfort during a transient in metabolic rate.

2.1.2 METHOD 1 - USE OF FIGURE 2

The logic of the controller using figure 2 was developed as follows:

$$\Delta T_{in_1} = K_1 \left(T_{in}' - \bar{T}_{in_1}\right) \tag{1}$$

where ΔT_{in_1} = the adjustment signal to the final control element, T_{in} (set point for the inlet coolant temperature to the LCG), calculated from the method using figure 2.

K_1 = The proportional gain constant for the method using figure 2.

T_{in}' = The current inlet temperature to the LCG.

$\bar{T}_{in_1}$ = The inlet temperature at steady state comfort read off figure 2 as a function of the currently measured ΔT.

2.13 METHOD 2 - USE OF FIGURE 3

The logic of the controller using figure 3 was as follows:

$$\Delta T_{in_2} = K_2 \left(\overline{\Delta T}_{in_2}\right) \tag{2}$$

where

ΔT_{in_2} = The adjustment signal to the final control element T_{in} calculated from the method using figure 2.

K_2 = The proportional gain constant for this method.

$\overline{\Delta T}_{in_2}$ = The changes in the inlet temperature based on figure 3.

$\overline{\Delta T}_{in_2}$ is read from figure 3 in the following manner. dT_{in}/dt is calculated (the changes in inlet temperature with time). $d\Delta T/dt$ is read from figure 3 as the expected change in ΔT $(\overline{\Delta\Delta T})$ during the same period of time. Since the same period of time is used, $\overline{\Delta\Delta T}$ is read as a function of ΔT_{in}. The actual change in ΔT $(\Delta\Delta T')$ from the expected $\overline{\Delta\Delta T}$ is then calculated. A calculation of the deviation $(\delta\Delta\Delta T)$ of the actual $\Delta\Delta T'$ from the expected $\overline{\Delta\Delta T}$ is made as follows:

$$\delta\Delta\Delta T = \Delta\Delta T' - \overline{\Delta\Delta T} \qquad (3)$$

$\delta\Delta\Delta T$ is the main error signal for this method. Error derivitive and error integral compensation were also added:

$$\delta\Delta\Delta T = \left(\Delta\Delta T' - \overline{\Delta\Delta T}\right) + K_3 \frac{d(\delta\Delta\Delta t)}{dt} + K_4 \int \delta\Delta\Delta T \, dt \qquad (4)$$

where

$$\delta\Delta\Delta T = \Delta\Delta T' - \overline{\Delta\Delta T} \text{ (eq. (3)).}$$

K_3 = the gain constant for error derivative compensation.

$\frac{d(\delta\Delta\Delta T)}{dt}$ = the error derivative compensation.

K_4 = the gain constant for the error integral compensation.

$\delta\Delta\Delta T dt$ = the error integral compensation.

The total error signal $\delta\Delta\Delta T$ is then used on the $\Delta\Delta T/\Delta T$ curve (fig. 3) to determine the adjustment to the final control element, T_{in}, by reading $\overline{\Delta T}_{in_2}$. $\overline{\Delta T}_{in_2}$ is then applied in eq. (2) to determine the adjustment to the final control element supplied by this method.

2.1.4 FINAL TOTAL CONTROLLER SIGNAL COMBINED FROM FIGURE 2 AND FIGURE 3 METHODS

The two methods described in eqs. (1) and (2) are then combined to give a final calculated value to the final control element, T_{in}:

$$T_{in} = T_{in}' + \left(\frac{\Delta T_{in_1} + \Delta T_{in_2}}{2}\right)$$

where T_{in}' is the current value of the final control element, the inlet LCG coolant temperature set point.

2.1.5 NEGLECTED CONTROLLER CONSIDERATIONS

Sensor response times, controller deadband, and speed of the final control element were neglected. It should be pointed out that the final control element is the set point for the inlet temperature to the LCG. Another controller would be required to operate the diverter valve bypassing coolant flow around the sublimator in the portable life support system (PLSS) to control the actual LCG inlet temperature. The delay and logic of this controller was neglected in the program and the inlet temperature of the LCG was set instantly to the set point required.

Output differential and integral compensation were attempted in both methods (eqs. 1 and 2). Lack of time prevented the development of gain constants that would improve controller results and these items were not incorporated into the test logic. Error differential and integral compensation in method 1 was never tried for lack of time.

Controller logic was based on Reference 3, pages 6-SERVO-1 through 6-SERVO-20.

2.1.6 PROGRAM CODE AND SAMPLE INPUT

Appendix A shows the program edits used to add the controller logic to Program J196. A nomenclature list is included.

Appendix B shows the input used to develop the necessary calculations from program J196 to do the required pretest predictions.

2.2 CONTROLLER LOGIC VERIFICATION AND PRETEST PREDICTIONS

A 40-hour metabolic profile was run on the J196 program, and values for the gain constants K_1, K_2, K_3 and K_4 were varied to obtain optimum controller action. Figures 4 and 5 show the best results that were obtained before an actual hardware test of a simulated controller was run. Figure 4 shows the metabolic profile vs. time. On the same graph, the controller selected inlet temperature and the resulting LCG ΔT are plotted. Figure 5 shows the resulting heat stored vs. time and how it compares to the comfort limits. On the same graph, controller action is shown by a plot of LCG inlet temperature vs. time.

The best values for the controller parameters resulting from these computer runs were as follows:

a. Values for the inlet temperature vs. LCG ΔT at steady state comfort were taken from figure 2.

b. Values for $\Delta\Delta T$ vs. ΔT while tracking perfect comfort were taken from figure 3.

c. Values for K_1, K_2, K_3 and K_4 were set at 0.085, 2.6, 0.0000001, and 0.01, respectively.

Pretest predictions of the controller test profile were run using the best controller logic achieved to that point. Metabolic rate levels were proposed to be 15 minutes each of 800, 2000, 400, and 1600 Btu/hr. Results are shown in figure 6. This graph shows heat stored vs. comfort limits. Valve action is shown by plotting inlet LCG temperature for expected test conditions. Recommendations for the test simulated controller included the following:

a. Set point values for the two curves were set at the figure 2 and 3 values as before.

b. K_1, K_2, K_3, and K_4 values were set at 0.0952, 2.912, 0.0000001, and 0.01, respectively.

3. CONCLUSIONS AND RECOMMENDATIONS

3.1 CONCLUSIONS

It can be concluded from computer simulation that crewman comfort can be assured by using automatic control of the inlet temperature of the coolant into the LCG when input to the controller consists of measurements of the LCG inlet temperature and ΔT. Subsequent tests using a facsimile of the control logic developed in the computer program confirmed the feasibility of such a design scheme.

Automatic comfort control has been demonstrated as a desirable product improvement. It is not a design requirement.

3.2 RECOMMENDATIONS

This controller should be fabricated and tested if funds can be made available for product improvement or if some reason is discovered that makes the inclusion of the device mandatory.

Design of the controller should include manual adjustment for shifting the curves from figures 2 and 3 to conform to physical changes such as a heat leak or inlet suit ventilation conditions and to compensate for personal preferences in comfort level. Design provisions should also be included in the PLSS hardware to allow that the controller be bypassed and that manual control of the diverter valve be available.

Final values of K_1, K_2, K_3, and K_4 should be determined by test. Final values for curves 2 and 3 can also be fine-tuned in testing. Output differential and integral compensation should be tested on both methods and error differential and integral compensation tried on method 1.

Recommendations for controller logic considerations were taken from reference 3, pages 6-SERVO-1 through 6-SERVO-20.

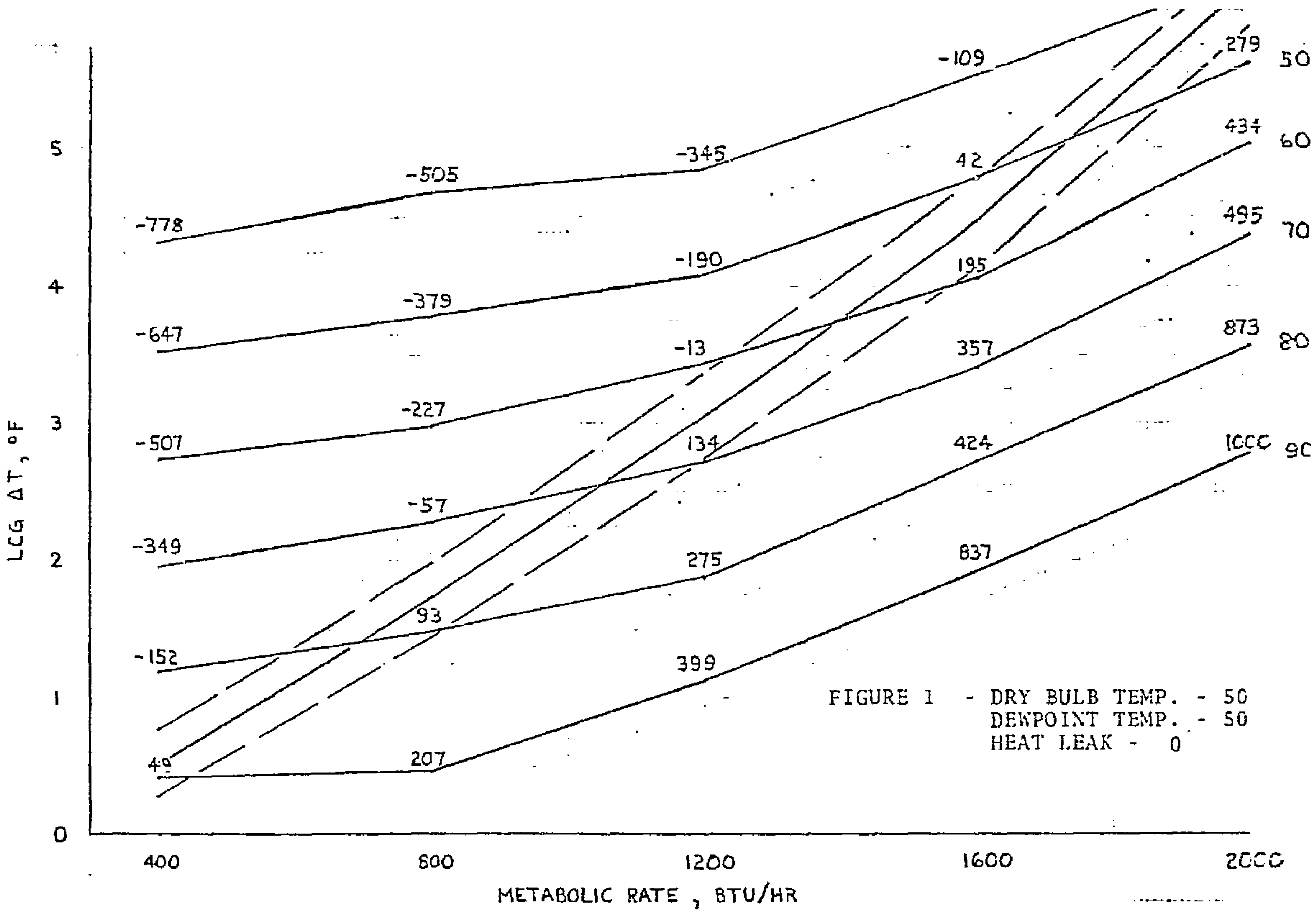
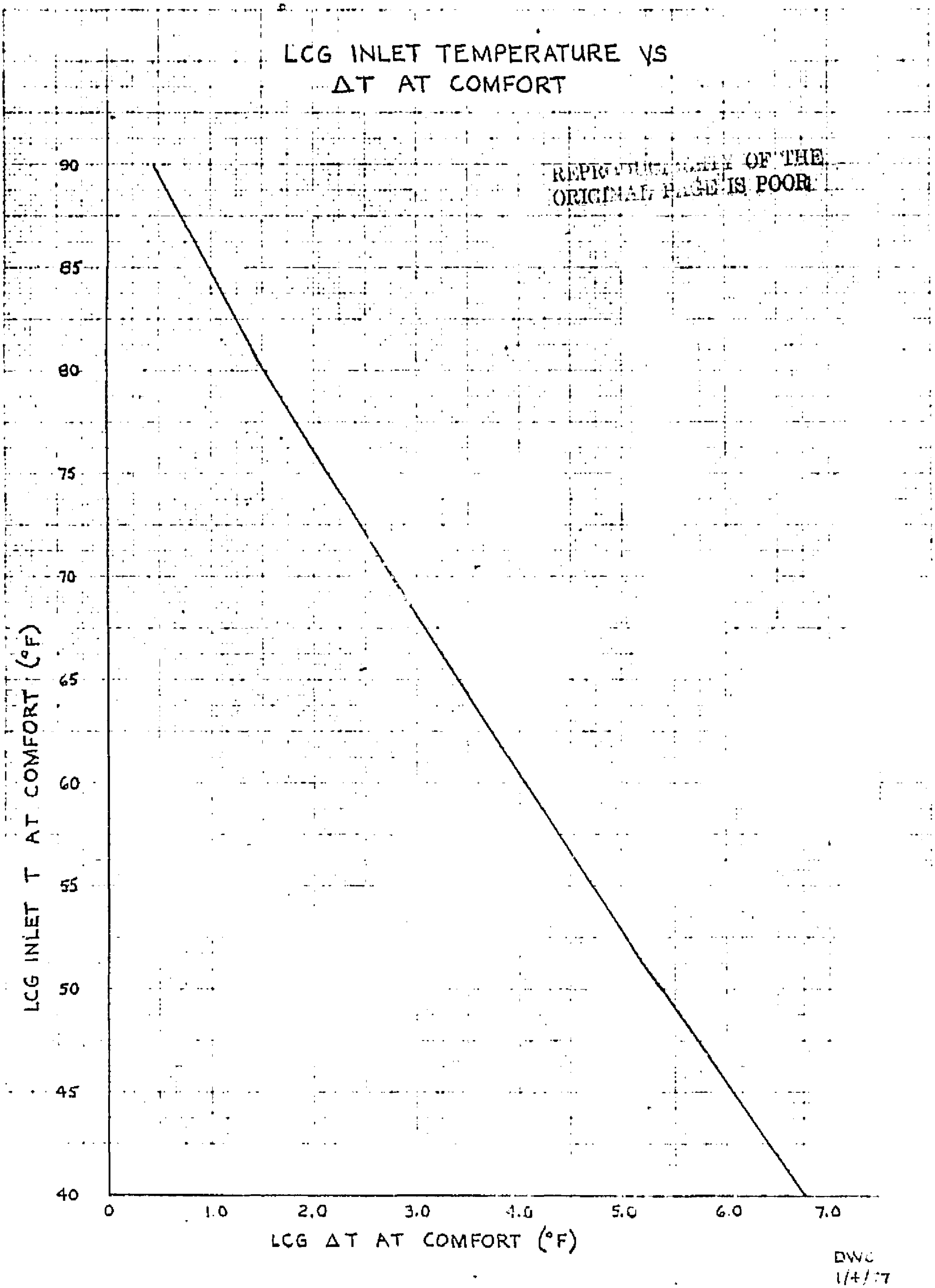


FIGURE 1 - DRY BULB TEMP. - 50
DEWPOINT TEMP. - 50
HEAT LEAK - 0



LCG INLET TEMPERATURE VS ΔT AT COMFORT

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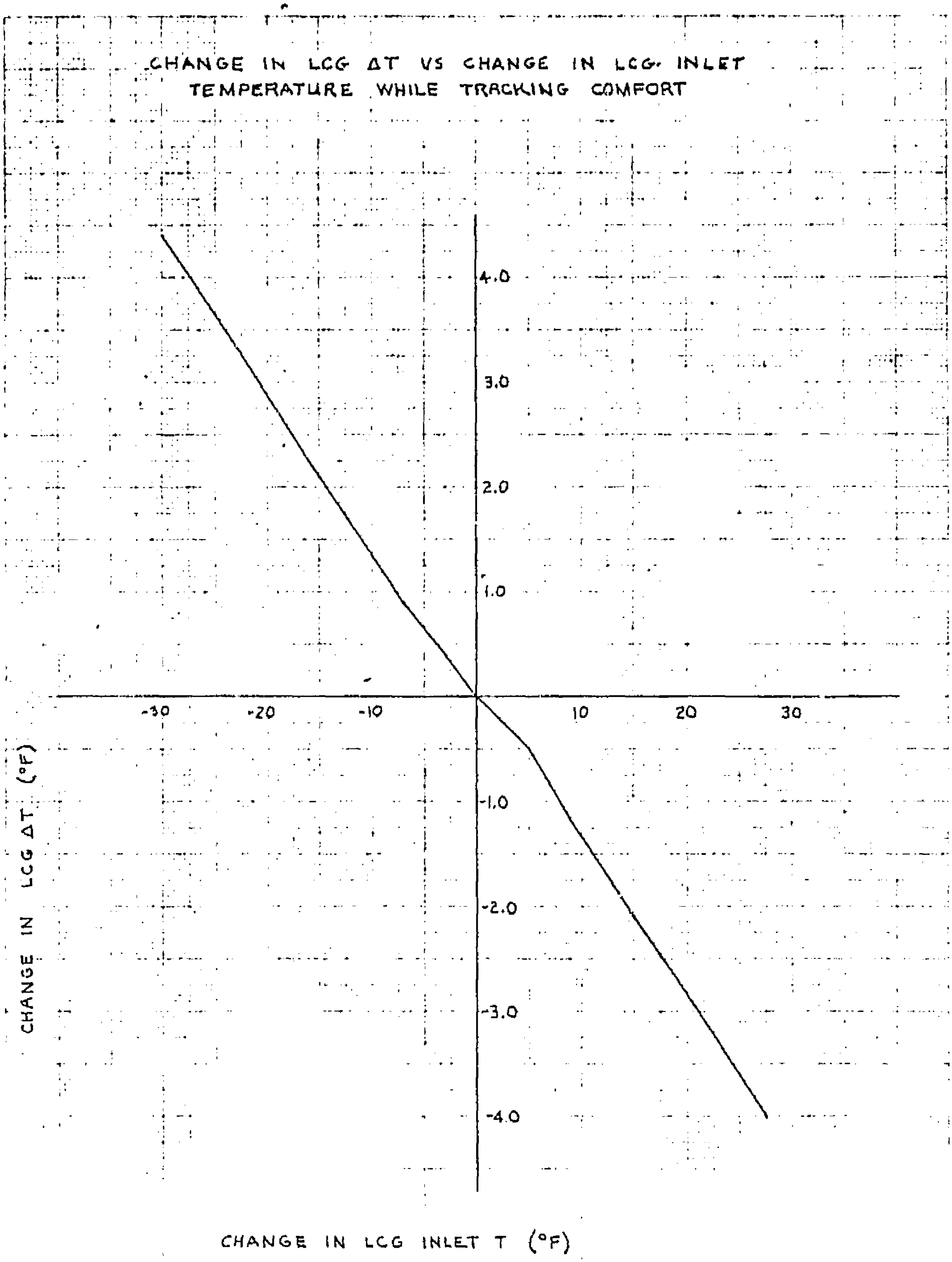

CHANGE IN LCG ΔT VS CHANGE IN LCG INLET TEMPERATURE WHILE TRACKING COMFORT

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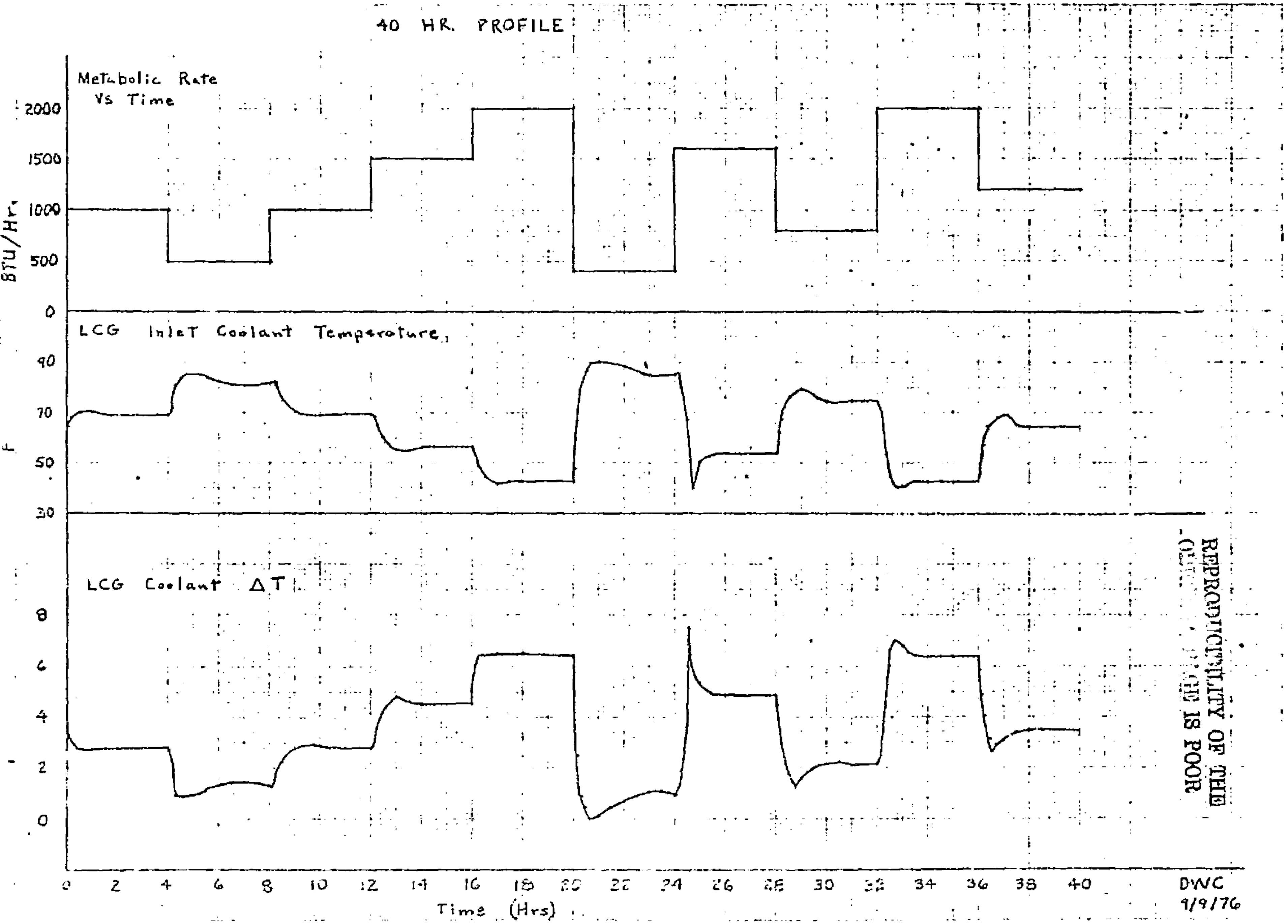
40 HR. PROFILE
Metabolic Rate Vs Time
BTU/Hr.
2000
1500
1000
500
0
LCG InleT Coolant Temperature,
F
90
70
50
30
LCG Coolant ΔT
8
6
4
2
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
Time (Hrs)
DWC
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FIGURE 4

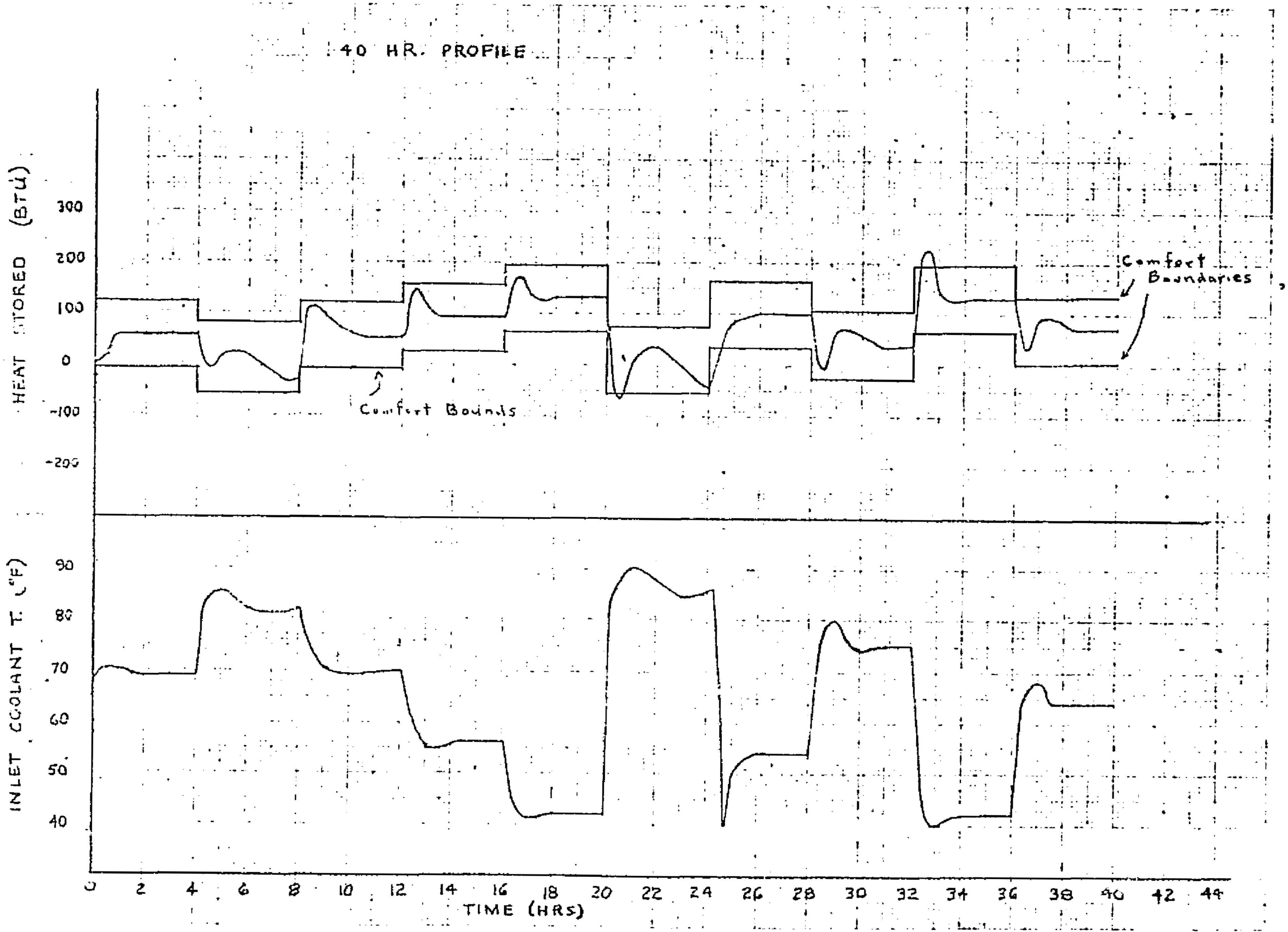

FIGURE 5

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Shuttle EMU Simulated
Controller Test

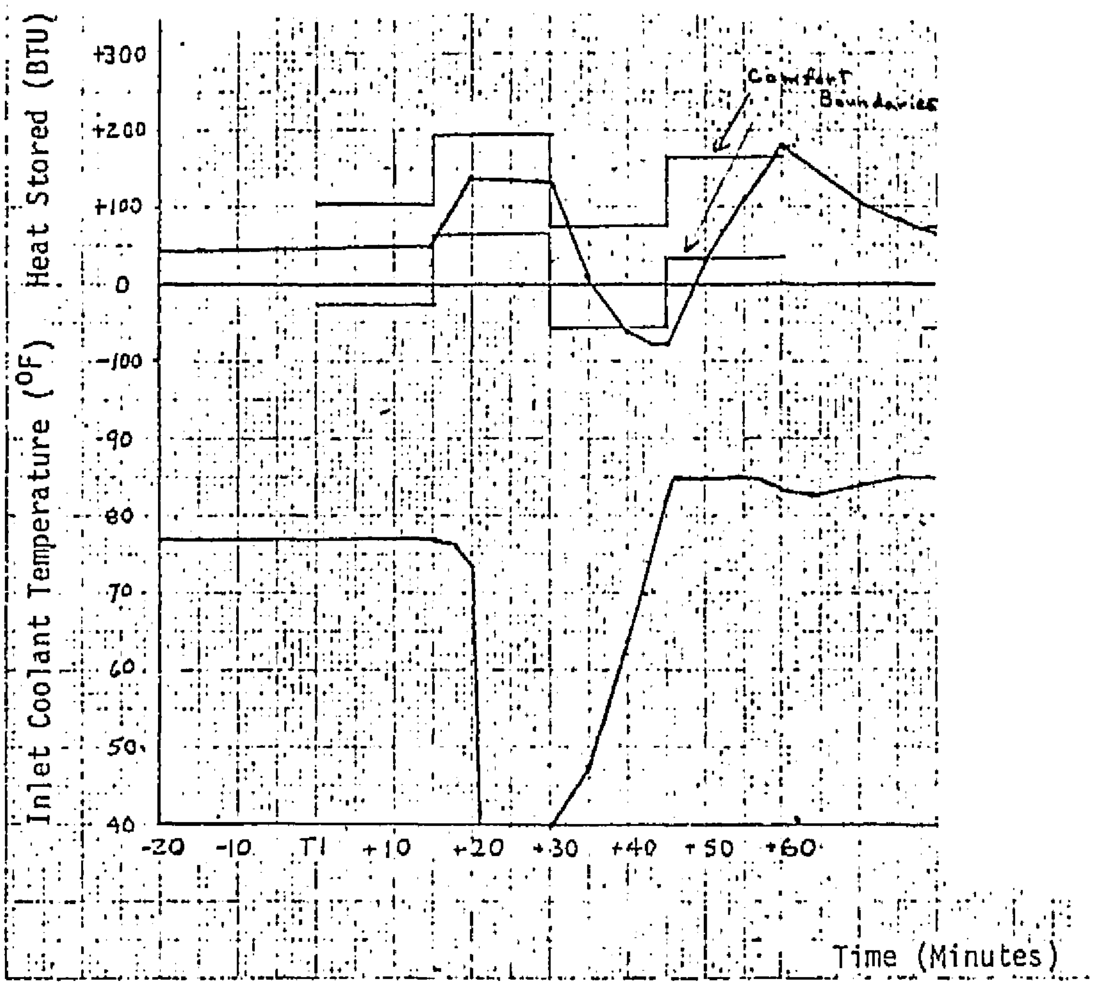

FIGURE 6

REFERENCES

1. Morgan, Lois W., et al: 41-Node Transient Metabolic Man Program, LEC/672-23-030031, May 1970.

2. Cook, D. W.: EMU Comfort Reference Data, TM-675-44-00103, August 25, 1970

3. Barker, R. S., et al: G-189A Generalized Environmental/Thermal Control and Life Support Systems Computer Program, McDonnell Douglas Contract NAS9-10330, September 1971.

APPENDIX A

PROGRAM EDITS TO MODEL THE PROPOSED CONTROLLER

(NOMENCLATURE LIST IS INCLUDED)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
 0125          .            CCTW(50),CCMODE(50)                                          000001
 0126           DIMENSION CCDLDL(16),CCDTWI(16)                                      NEW000001
 0127           DIMENSION CCDELT(12),CCDLOP(12)                                      NEW000001
 0127     C     IF ANY CURVE DIMENSION IS CHANGED CRVS MUST BE REDIMENSIONED            000001
 0127     C     IF NEW CURVES ARE ADDED NCRV,ICRVP,CRVS, AND CRVL SHOULDBE UPDATED      000001
 0130           EQUIVALENCE( CRVL(1),CQASRB),( CRVL(2),CMODE),( CRVL(3),CTGIN),        000001
 0130          1           ( CRVL( 4),CTDEW ),( CRVL( 5),CTWI  ),( CRVL( 6),CPCAP ),    000001
 0130          2           ( CRVL( 7),CPSC  ),( CRVL( 8),CPO2  ),(CRVL( 9),CPM    ),     000001
 0130          3           ( CRVL(10),CUEFF ),( CRVL(11),CWF   ),( CRVL(12),CCFMS ),    000001
 0130          4           ( CRVL(13),CAKS  ),( CRVL(14),DAKS  ),( CRVL(15),CTDEWC),    000001
 0130          5           ( CRVL(16),CTCAB ),( CRVL(17),CVCAB ),( CRVL(18),CTW   )     000001
 0131           EQUIVALENCE(ICRVP(1),NPCASB),(ICRVP(2),NPMODE),(ICRVP(3),NPTGIN),      000001
 0131          1           (ICRVP( 4),NPTDEW),(ICRVP( 5),NPTWI ),(ICRVP( 6),NPPCAB),    000001
 0131          2           (ICRVP( 7),NPPSC ),(ICRVP( 8),NPPO2 ),(ICRVP( 9),NPRM  ),    000001
 0131          3           (ICRVP(10),NPUEFF),(ICRVP(11),NPWF  ),(ICRVP(12),NPCFMS),    000001
 0131          4           (ICRVP(13),NPAKS ),(ICRVP(14),OPAKS ),(ICRVP(15),NPTDWC),    000001
 0131          5           (ICRVP(16),NPTCAB),(ICRVP(17),NPVCAP),(ICRVP(18),NPTW  )     000001
 0132           EQUIVALENCE(CRVS(1,1),CCCASB(1,1)),(CRVS(1,11),CCMODE),                000001
 0132          1             (CRVS(1,12),CCTGIN),      (CRVS(1,13),CCTDEW),              000001
 0132          2             (CRVS(1,14),CCTWI ),      (CRVS(1,15),CCPCAB),              000001
 0132          3             (CRVS(1,16),CCPSC ),      (CRVS(1,17),CCPO2 ),              000001
 0132          4             (CRVS(1,18),CCRM  ),      (CRVS(1,19),CCUEFF),              000001
 0132          5             (CRVS(1,20),CCWF  ),      (CRVS(1,21),CCCFMS),              000001
 0132          6             (CRVS(1,22),CCAKS ),      (CRVS(1,23),DDAKS ),              000001
 0132          7             (CRVS(1,24),CCTDWC),      (CRVS(1,25),CCTCAB),              000001
 0132          8             (CRVS(1,26),CCVCAB),      (CRVS(1,27),CCTW  )               000001
 0133           DATA(TSET(I),I=1,41)/98.6,97.6,97.0,96.6,98.8,98.3,95.9,94.4,96.1,     000001
 0133          .                     95.1,94.1,93.7,96.1,95.1,94.1,93.7,97.6,96.5,     000001
 0133          .                     95.1,94.5,97.6,96.5,95.1,94.5,95.9,95.7,95.6,     000001
 0133          .                     95.5,95.9,95.7,95.6,95.5,95.8,95.5,95.7,95.5,     000001
 0133          .                     95.0,95.5,95.7,95.5,98.5/                         000001
 0135           DATA(C(I),I=1,41)/6.67,1.488,0.496,0.535,20.9,34.9,9.42,2.69,1.382     000001
 0135          .                ,3.35,0.644,0.484,1.352,3.35,0.644,0.484,4.4,10.2     000001
 0135          .                ,1.59,1.192,4.4,10.2,1.58,1.192,0.1566,0.0738,         000001
 0135          .                 0.0992,0.184,0.1566,0.0738,0.0992,0.184,0.2645,       000001
 0135          .                 0.0738,0.148,0.247,0.2645,0.0738,0.148,0.247,         000001
 0135          .                 4.94/                                                000001
 0137           DATA( PCFLO(J),J=1,5)/.2,.125,.125,.275,.275/                          000001
 0141           DATA NB/71*0./,ARI/15.5/                                              000001
 0144           DATA(CCDELT(J),J=1,12)/0.46,90.0,1.51,80.0,2.75,70.0,4.05,60.0,      NEW000001
 0144          1                   5.37,50.0,6.75,40.0/                              NEW000001
 0146           DATA(CCDLDL(J),J=1,16)/-4.0,27.5,-1.2,9.0,-0.5,5.0,0.0,0.0,0.4,      NEW000001
 0146          1                      -3.0,0.9,-7.0,2.1,-15.0,4.4,-30.0/             NEW000001
 0150           DATA(CCDTWI(J),J=1,16)/-30.0,4.4,-15.0,2.1,-7.0,0.9,-3.0,0.4,0.0,    NEW000001
 0150          1                      0.0,5.0,-0.5,9.0,-1.2,27.5,-4.0/               NEW000001
 0152           DATA DELTAF/20.0/                                                    NEW000001
 0152     C                                                                            000001
 0152     C   DEFINITION OF BODY SEGMENT TEMPERATURE SUBSCRIPTS                          000001
 0152     C   T(1)  = HEAD CORE          T(2)  = HEAD MUSCLE       T(3)  = HEAD FAT       000001
 0152     C   T(4)  = HEAD SKIN          T(5)  = TRUNK CORE        T(6)  = TRUNK MUSCLE   000001
 0152     C   T(7)  = TRUNK FAT          T(8)  = TRUNK SKIN        T(9)  = RIGHT ARM CORE 000001
 0152     C   T(10) = RIGHT ARM MUSCLE   T(11) = RIGHT ARM FAT     T(12) = RIGHT ARM SKIN 000001
 0152     C   T(13) = LEFT ARM CORE      T(14) = LEFT ARM MUSCLE   T(15) = LEFT ARM FAT   000001
 0152     C   T(16) = LEFT ARM SKIN      T(17) = RIGHT LEG CORE    T(18) = RIGHT LEG MUSCLE 000001
 0152     C   T(19) = RIGHT LEG FAT      T(20) = RIGHT LEG SKIN    T(21) = LEFT LEG CORE  000001
 0152     C   T(22) = LEFT LEG MUSCLE    T(23) = LEFT LEG FAT      T(24) = LEFT LEG SKIN  000001
 0152     C   T(25) = RIGHT HAND CORE    T(26) = RIGHT HAND MUSCLET(27) = RIGHT HAND FAT  000001
```

```
00302      302*     C       SO THAT CRANE CAN STEP MORE ACCURATELY                                                   000220
00304      303*             CALL DISCON                                                                              000222
00305      304*         245 CONTINUE                                                                                 000225
00306      305*             ENDONX=.TRUE.                                                                            000225
00307      306*             JT=JT+1                                                                                  000226
00310      307*             XHATAR(JT)=SETI/60.                                                                      000231
00311      308*             IF(JT .EQ. 1)GO TO 247                                                                   000235
00311      309*     C       PUT THE XHAT VALUES IN ASCENDING ORDER                                                   000235
00313      310*             CALL ASCEND(XHATAR,JT)                                                                   000240
00314      311*         247 CONTINUE                                                                                 000245
00315      312*             XHAT=XHATAR(1)                                                                           000245
00316      313*             IXH=1                                                                                    000246
00317      314*             PREC=5.                                                                                  000250
00320      315*             IF(ICOND .EQ. 0) PREC=3.                                                                 000252
00322      316*             OLDT=-1.                                                                                 000256
00323      317*             DTIME=DT/60.                                                                             000260
00324      318*             MIN=3                                                                                    000263
00325      319*             VPPCAB = VPP(TDEWC)                                                                      000265
00326      320*             SPHCAB=VPPCAB*18/(PCAB*29.)                                                              000271
00327      321*             TOTCO2=0.0                                                                               000276
00330      322*             TOTO2=0.0                                                                                000277
00331      323*             TOTWCN=0.0                                                                               000300
00332      324*             FDWTR=0.0                                                                                000301
00333      325*         837 CONTINUE                                                                                 000303
00334      326*             H=DTIME                                                                                  000303
00335      327*             INITL=0                                                                                  000304
00336      328*             HC=H                                                                                  NEW000305
00337      329*             AR=ARI                                                                                   000307
00340      330*             IF(MODE .GT. 0) AR=AC                                                                    000311
00342      331*             IF(MODE-1)21,22,23                                                                       000316
00345      332*          21 WRITE(6,117)                                                                             000322
00347      333*       117   FORMAT(16X,17HSHIRTSLEEVES MODE/)                                                        000327
00350      334*             GO TO 26                                                                                 000327
00351      335*       22    WRITE(6,118)                                                                             000331
00353      336*       118   FORMAT(18X,18HNORMAL SUITED MODE/)                                                       000335
00354      337*             GO TO 26                                                                                 000335
00355      338*       23    IF (MODE .GT. 2) GO TO 24                                                                000337
00357      339*             EVA = .TRUE.                                                                             000342
00360      340*             WRITE(6,119)                                                                             000344
00362      341*       119   FORMAT(21X, 8HEVA MODE/)                                                                 000351
00363      342*             GO TO 26                                                                                 000351
00364      343*       24    WRITE(6,120)                                                                             000353
00366      344*       120   FORMAT(13X,27HSUITED WITH HELMET OFF MODE/)                                              000360
00367      345*        26   IF (IPLOP) WRITE(6,1001)                                                                 000360
00372      346*       1001 FORMAT(18X,12HPOST LANDING)                                                               000366
00373      347*             IF(.NOT. IPLOP) GO TO 1010                                                               000366
00375      348*             WRITE(6,1702)RGAS,TATM,VOLCAB,PO2A,PN2A,CPA,NUMEN,PA,AREAW,                              000370
00375      349*            * TDEWA,CFMC                                                                              000370
00412      350*       1702 FORMAT(' ATMOSPHERIC GAS CONSTANT, LBF-FT/(LBM-DEG R)------',F9.3/                        000411
00412      351*           1         ' DRYBULB TEMP. OF ATMOSPHERE, DEG.F---------------',F9.3/                       000411
00412      352*           2         ' VOLUME OF CABIN, CU FT---------------------------',F9.3/                       000411
00412      353*           3         ' ATMOSPHERIC OXYGEN PARTIAL PRESSURE, PSIA---------',F9.3/                      000411
00412      354*           4         ' ATMOSPHERIC NYTROGEN PARTIAL PRESSURE, PSIA-------',F9.3/                      000411
00412      355*           5         ' SPECIFIC HEAT OF ATMOSPHERE, BTU/(LBM-DEG F)------',F9.3/                      000411
00412      356*           6         ' NUMBER OF MEN--------------------------------------',I9/                       000411
00412      357*           7         ' ATMOSPHERIC PRESSURE, PSIA-------------------------',F9.3/                     000411
00412      358*           8         ' CABIN WALL AREA, SQ FT-----------------------------',F9.3/                     000411
```

```
01002           WRITE(6,99)                                              001226
01004           MODEC=MODE                                               001233
01005           MODE=MODEC                                               001235
01006           EVA=.FALSE.                                              001237
01007           GO TO 887                                                001240
01010     886   CONTINUE                                                 001242
01011           IF (CTGIN) CALL LAGIN (1,CCTGIN,NPTGIN,2,TIME,TGIN)      001242
01013           IF (CTDEW) CALL LAGIN (2,CCTDEW,NPTDEW,2,TIME,TDEW)      001253
01015           IF (CTWI ) CALL LAGIN (3,CCTWI,NPTWI,2,TIME,TWI)         001265
01017           IF (CPCAB) CALL LAGIN (4,CCPCAB,NPPCAB,2,TIME,PCAB)      001277
01021           IF (CPGC ) CALL LAGIN (5,CCPGC,NPPGC,2,TIME,PG)          001311
01023           IF (CPO2 ) CALL LAGIN (6,CCPO2,NPPO2,2,TIME,PO2)         001323
01025           IF (CRM  ) CALL LAGIN (7,CCRM,NPRM,2,TIME,RM)            001335
01027           IF (CUEFF) CALL LAGIN (8,CCUEFF,NPUEFF,2,TIME,UEFF)      001347
01031           IF(.NOT. CWF) GO TO 380                                  001361
01033           WFOLD=WF                                                 001363
01034           CALL LAGIN(9,CCWF,NPWF,2,TIME,WF)                        001365
01035           WDOT1=WDOT1*WF/WFOLD                                     001375
01036     380   CONTINUE                                                 001402
01037           IF (CCFMS) CALL LAGIN (10,CCCFMS,NPCFMS,2,TIME,CFMS)     001402
01041           IF (.NOT. CAKS) GO TO 730                                001413
01043           CALL LAGIN (11,CCAKS,NPAKS,2,TIME,AKST)                  001415
01044           DO 725 I=1,10                                            001430
01047           AKS(I)=AKST                                              001430
01050     725   CONTINUE                                                 001432
01052           IF(DAKS)CALL LAGIN(12,DDAKS,DPAKS,2,TIME,AKS(10))        001432
01054     730   IF (.NOT. CQASRB) GO TO 400                              001445
01056           DO 726 I=1,10                                            001452
01061           CALL LAGIN(13,CCQASR(1,I),NPQASR,2,TIME,QASRB(I))        001452
01062     726   CONTINUE                                                 001467
01064     400   CONTINUE                                                 001467
01065           IF(TRAN .OR. IQ.EQ. 0) GO TO 430                         001467
01067           CALL TMATRX                                              001474
01070     430   CONTINUE                                                 001477
01071           DLTAT1=DELTAT                                         NEW001477
01072           WILDLT=WDLDLT                                         NEW001500
01073           CALL SUIT                                                001502
01074           DELTAT=TWO-TWI                                        NEW001504
01075           TWI1=TWI                                              NEW001507
01076           DLDLT=DELTAT-DLTAT1                                   NEW001511
01077           EDLDLT=EDLDLT*H/HO                                    NEW001513
01100           WDLDLT=DLDLT-EDLDLT                                   NEW001517
01101           DDLDLT=~~0.0010001*~~(WDLDLT-WILDLT*H/HO)/H           NEW001521
01102           TDLDLT=TDLDLT+WDLDLT*H                                NEW001530
01103           WDLDLT=WDLDLT+DDLDLT+0.01*TDLDLT                      NEW001533
01104           CALL LAGIN(9,CCDLDL,8,2,~~WDLDLT,~~DTWI)              NEW001537
01105           TWI=TWI+2.6*DTWI                                      NEW001547
01106           CALL LAGIN(9,CCDELT,6,2,DELTAT,TWI2)                  NEW001553
01107           TWI2=TWI1+0.035*(TWI2-TWI1)                           NEW001563
01110           TWI=(TWI+TWI2)/2.0                                    NEW001570
01111           IF(TWI.GT.93.0)TWI=93.0                               NEW001573
01113           IF(TWI.LT.40.0)TWI=40.0                               NEW001601
01115           DTWI=TWI-TWI1                                         NEW001607
01116           CALL LAGIN(10,CCDTWI,8,2,DTWI,EDLDLT)                 NEW001612
01117           HO=H                                                  NEW001622
01120           O2RATE= (0.0001708-((PO-0.707)/0.293*0.0000123))*RM      001624
01121           CO2RAT=O2RATE*44.0/32.0*RQ                               001633
```

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

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  1244    701*          KOUNTR = KOUNTR+24                                                          002135
  1245    702*    704   IF (IMPAIR .AND. QSTOR .GT. 1000) GO TO 706                                  002141
 01247    703*          GO TO 705                                                                   002151
 01250    704*    706   IF (KOUNTR .GT. 24) GO TO 709                                               002153
 01252    705*          WRITE (6,602)                                                               002156
  1254    706*          WRITE(6,601)                                                                002163
  1255    707*          GO TO 714                                                                   002170
  1257    708*     709  WRITE(6,99)                                                                 002172
 01261    709*          WRITE(6,601)                                                                002176
 01263    710*    714   WRITE (6,608)                                                               002204
 01265    711*          TERM=.TRUE.                                                                 002210
 01266    712*          GO TO 14                                                                    002212
 01267    713*     705  CONTINUE                                                                    002214
 01270    714*          WRITE(6,113) PTIM,TGOUTS,SHSO,T(1),T(72),TISAV,TOSAV,QTSUIT,SOUG,           002214
 01270    715*         1CEVAP,TOTL,STORAT,QSHIV,QSTOR                                               002214
 01310    716*          SUBDOT = SUBOUT - SUBIN                                                  -01002236
  1311    717*          OTPP=760.0/14.7*PH2OSO                                                      002241
 01312    718*          TDEWOT=DEWPT(OTPR)                                                          002244
 01313    719*          OTPPI=PG*SHSO*32.0/18.0*760.0/14.7                                          002250
 01314    720*          TDWOT1=DEWPT(OTPRI)                                                         002257
 01315    721*          SATPRS=VPP(TGOUTS)                                                          002263
 01316    722*          RELHUM=PH2OSO/SATPRS                                                        002267
 01317    723*          IF(LCG) WRITE(6,999) TWI,TWO,DELTAT,TDEW,TGIN,TOTO2,TOTCO2,TOTWCN,          002272
 01317    724*         1                      FDWTF,RM,WF                                            002272
  1330    725*          NAMELIST/WO1/TWI1,DLTAT1,DLDLT,WDLDLT,DTWI,EDLDLT,TWI2                   NEW002314
  1330    726*          WRITE(6,WO1)                                                             NEW002314
 01341    727*          IF (MODE .EQ. 1 .OR. MODE .EQ. 2) WRITE(6,2002) HCO2MH                      002320
 01343    728*          IF (IPLOP) WRITE(6,1603) TCAB,TDEWC,CO2MMH                                  002342
 01353    729*    1603  FORMAT(15H   CABIN TEMP =,F7.2, 6H DEG F,18H   DEWPOINT TEMP =,             002354
 01353    730*         1        F7.2, 6H DEG F,17H   CO2 PRESSURE =,F7.2, 6H MM HG/)                002354
 01354    731*          QLATTR = QLAT(1) + QLAT(5) + QLAT(2) + QLAT(3) + QLAT(6)                    002354
 01355    732*          IF (IPLOP) GO TO 1605                                                       002362
 01357    733*          IF (KOUNTR .EQ. 48) GO TO 1606                                              002364
  1361    734*          KOUNTR = KOUNTR + 3                                                         002367
 01362    735*          GO TO 1608                                                                  002372
  1363    736*    1606  WRITE (6,112)                                                               002374
 01365    737*          KOUNTR = 0                                                                  002400
 01366    738*          GO TO 1608                                                                  002401
 01367    739*    1605  IF (KOUNTR .EQ. 48) GO TO 1607                                              002403
 01371    740*          KOUNTR = KOUNTR + 4                                                         002405
 01372    741*          GO TO 1608                                                                  002410
 01373    742*    1607  WRITE (6,112)                                                               002412
 01375    743*          KOUNTR = 0                                                                  002416
 01376    744*    1608  IF(TRAN) GO TO 490                                                          002420
 01400    745*          ASSIGN 14 TO IJM                                                            002421
 01401    746*          ASSIGN 12 TO IJMP                                                           002423
 01402    747*          GO TO 780                                                                   002425
 01403    748*     490  CONTINUE                                                                    002427
 01404    749*          IF(JT .EQ. 0 .OR. ENDONX)GO TO 915                                          002427
 01406    750*          IXH=IXH+1                                                                   002434
 01407    751*          IF(IXH .LE. JT)GO TO 910                                                    002437
 01411    752*          JT=0                                                                        002442
 01412    753*          GO TO 915                                                                   002443
 01413    754*     910  ENDONX=.TRUE.                                                               002445
 01414    755*          XHAT=XHATAR(IXH)                                                            002447
 01415    756*     915  CONTINUE                                                                    002452
 01415    757*   C      CHECK IF CRANE HAS SET THE FLAG ENDONX TO FALSE TO INDICATE THE             002452
```

NOMENCLATURE OF VARIABLES APPEARING IN CONTROLLER EDITS

Program name	Document engineering symbol	Description
CCDELT	Figure 2	Curve of LCG ΔT vs. inlet temperature at comfort (both in ^{o}F).
CCDLDL	Figure 3	Curve of change in LCG ΔT vs. change in LCG inlet temperature while tracking perfect comfort with the changes in inlet temperature as the dependent variable (all ^{o}F).
CCDLDP	not currently used.	
CCDTWI	Figure 3	Curve of change in LCG ΔT vs. change in LCG inlet temperature while tracking perfect comfort with the change in LCG ΔT as the dependent variable (all ^{o}F).
DELTAT	LCG ΔT	Difference in the liquid cooled garment inlet and outlet coolant temperature (^{o}F).
DDLDLT	$d\Delta\Delta T/dt$	Error differential compensation ($^{o}F/hr$).
DLDLT	$\Delta\Delta T$ or $d\Delta T/dt$	Change in LCG ΔT with respect to time. (Time cancels out on the $\Delta\Delta T$ vs. ΔT curve) ($^{o}F/hr$ or ^{o}F).
DLTAT1	-----	Difference in the liquid cooled garment inlet and outlet coolant temperatures calculated in previous time step (^{o}F).
DTWI (first appearance)	ΔT_{in_2}	The adjustment signal to the final control element using method 2, figure 3, eq. (2).
DTWI (second appearance)	-----	Final complete adjustment signal to the final control element, T_{in}.

NOMENCLATURE OF VARIABLES APPEARING IN CONTROLLER EDITS (Continued)

Program name	Document engineering symbol	Description
DTWI (second appearance)	dT_{in}/dt	Changes in LCG inlet temperature between current time increment and last (^{o}F/hr).
EDLDLT	$\overline{\Delta\Delta T}$	Expected change in LCG ΔT ($d\Delta T/dt$) that would accompany a change in LCG inlet temperature if perfect comfort were being tracked (^{o}F/hr).
H	dt	Current time increment (hr).
HO	-----	Previous time increment (hr).
RDLDLT	$\int \delta\Delta\Delta T \, dt$	Summation of $\delta\Delta\Delta T$ times the time increment (^{o}F/hr).
TWI (first appearance)	-----	New position of the final control element as calculated by method 2, figure 3, eq. (2) (^{o}F).
TWI (second appearance)	T_{in}	New position of the final control element (^{o}F).
TWI1	-----	Position of the final control element at the previous time increment (^{o}F).
TWI2	-----	Position of the final control element as calculated by method 1, figure 2, eq. (1).
WDLOLT	$\delta\Delta\Delta T$	Deviation of the actual change in LCG ΔT from the expected change in LCG ΔT
WILDLT	-----	WDLDLT at the previous time increment.

APPENDIX B

INPUT TO PROGRAM J196 TO BRING ABOUT THE NECESSARY CONTROLLER PRETEST PREDICTIONS AND EVALUATIONS

```
@ELT,ULL DATA2
ELT007 RL71-3 09/18/76 08:20:50 (1,2)
000001        000     $INPUT
000002        000             MODE=2,
000003  NEW   002      MODE=1,
000004        000     RM=1200.,
000005  NEW   002      RM=1000.0,
000006        000             UEFF=0.,
000007        000             AC=19.5,
000008  NEW   002      AP1=19.5,
000009  -01   000             G=0.,
000010        000             ALUG=0.0141,
000011        000     AKUG=.046,
000012        000             EUG=0.9,
000013        001     ACSUIT=9.22,2.91,2.91,6.38,6.38,0.77,0.77,1.19,1.19,1.85,
000014        001     ARSUIT=7.34,2.22,2.32,5.07,5.07,0.62,0.62,0.96,0.96,1.47,
000015        001     ALS=9*.0078,.021,
000016        001     AKS=9*.000383,.02155,
000017        001     EOS=9*0.91,.62,
000018        001     EIS=10*0.90,
000019        001     WS=15.60,4.89,4.89,10.82,10.82,1.22,1.22,1.95,1.95,2.75,
000020        001     CPS=9*0.22,0.30,
000021        000     GASRE=10*308.,
000022  NEW   002      GASRE=10*120.0,
000023        000             VF=0.0,
000024        000     VOLHMT=0.1968,
000025        000     CFMS=6.,
000026  NEW   002      CFMS=5.90,
000027        000     TGIN=60.,
000028  NEW   002      TGIN=45.0,
000029        000     TDEW=50.,
000030  NEW   002      TDEW=43.0,
000031        000             CPG=0.22,
000032        000     PG=3.65,
000033  NEW   002      PG=4.0,
000034        000     PG2=3.65,
000035  NEW   002      PG2=4.0,
000036  NEW   002      LCG=T,
000037  -01   000     WF=240.,
000038        000     TWI=40.,
000039  NEW   002      TWI=72.0,
000040        000             CPW=1.0,
000041        000     UAG=43.5,
000042        000     DT=0.05,
000043        000     PRINTI=5.0,
000044        000     SETI=600.,
000045  NEW   002      SETI=240.0,
000046  NEW   002      NCASES=25.0,
000047  NEW   002             STLPF=.TRUE.,
000048  NEW   002             RM=800.0,
000049  NEW   002             TWI=75.0,
000050  NEW   002             PRINTI=1.0,
000051        000     $END
000052  NEW   002     $INPUT
000053  NEW   002             RM=500.0,
000054  NEW   002           SETI=15.0,
000055  NEW   002             RM=800.0,
```

```
000056   NEW 002     $END
000057   NEW 002     $INPUT
000058   NEW 002           RM=1000.0,
000059   NEW 002          SETI=480.0,
000060   NEW 002          SETI=30.0,
000061   NEW 002          RM=2000.0,
000062   NEW 002     $END
000063   NEW 002     $INPUT
000064   NEW 002           RM=1500.0,
000065   NEW 002          SETI=720.0,
000066   NEW 002          SETI=45.0,
000067   NEW 002          RM=400.0,
000068   NEW 002     $END
000069   NEW 002     $INPUT
000070   NEW 002           RM=2000.0,
000071   NEW 002          SETI=960.0,
000072   NEW 002          SETI=60.0,
000073   NEW 002          RM=1600.0,
000074   NEW 002     $END
000075   -15 000    @PMD,B

END ELT.


@PREP
FURPUR 0026-09/18-08:26
```