The NASA Langley Research Center
0.3-Meter Transonic Cryogenic Tunnel
Microcomputer Controller Source Code

W. Allen Kilgore and S. Balakrishna
ViGYAN Inc.
Hampton, Virginia 23666-1325

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**Introduction**

The NASA Langley Research Center 0.3-m Transonic Cryogenic Tunnel (TCT) has been operational since 1973. It is a closed circuit fan driven pressure tunnel in which the heat generated by the fan operation is cancelled by injection of liquid nitrogen (LN$_2$) into the tunnel. The injected LN$_2$ evaporates into the tunnel and cools the tunnel resident nitrogen gas (GN$_2$) mass. The gaseous mass buildup and pressure variation caused by LN$_2$ injection is corrected by controlled discharge of warmer GN$_2$ tunnel gases. The gas temperature, pressure, and flow Mach number of the tunnel can be controlled by adjusting the LN$_2$ injection and the GN$_2$ discharge for a given fan speed.

In 1988 a microcomputer was installed at the 0.3-m TCT to control the temperature, pressure, LN$_2$ back pressure, fan speed, Mach number and Reynolds number. This system replaced the existing microprocessor control system. This new controller system consists of a PC AT clone with a 12 MHz CPU, an EGA video, a hard disk, a floppy disk, and an 8 channel digital to analog converter. This Controller was designed specifically for ease in modification and operational use. This system has now been operating for several thousand hours providing a safe and efficient control of the tunnel. (Ref. 1 and 2)

Since the Controller has been in use, the staff has gained an extensive knowledge of the Controller and its features. Through the operational use of the Controller several recommendations for improvements have been suggested. Many of these suggestions have been incorporated into the Controller and are described later in this document. The control laws and operations of the Controller have not changed from the original Controller.

The purpose of this document is to provide the source code listing of the 0.3-m TCT Controller which is in Appendix A. Also included is the source code listing for the tunnel simulator (Appendix B) and a complete listing of the variables used in each source code (Appendix C).
Controller Changes

Described below are the changes made to the original Controller. A reason and a description of the change are given for a better understanding of the improvements made to the Controller. Changes to the Controller software should be performed by a person who fully understands the BASIC language. This should be performed only with the knowledge and approval of the Facility Safety Head of the 0.3-m TCT.

Set Tunnel Operation Limits

A requested change was to have the ability for the user to set the tunnel operating limits. An example of this is to have the user set a maximum pressure limit of 50 psia. This limit is below the tunnel maximum operating pressure of 88 psia and is therefore an acceptable limit. With the user set 50 psia limit, the user would not be allowed to input pressures above 50 psia while operating the Controller. This ability to have the user set the tunnel operating limits required an addition to the beginning of the original Controller.

The Controller is now designed so that when the Controller is first executed a Maximum - Minimum Limits program is run which allows the user to set the operating limits of the tunnel. The user set limits must be within the operating envelope of the tunnel. This Maximum - Minimum Limits monitor display is shown in figure 1. This display is self-explanatory and operates using similar keystrokes as the Controller. (Ref. 2) The Maximum - Minimum Limits program allows the user to set a minimum temperature, maximum pressure, maximum fan speed, maximum Mach number, and maximum Reynolds number. The user can either start the Controller with the tunnel limits or the user set limits.

To set the pressure limit the user would strike the "P" key on the keyboard. This would cause a ",psia" to appear on the screen in the Set Maximum column. The user keys in the desired pressure limit and strikes the "Enter" key. If the desired limit is unusable, the program will warn the user of the problem and will not allow the Controller to be started. The other limits may be set by striking the appropriate T, N, M, or R keys on the keyboard. The Maximum - Minimum Limits program has several safety features which prevent the user from setting unacceptable or unsafe limits.

These user set limits are only enforced when the tunnel is in the automatic control
mode of the variable. For example, if the user set limit for pressure is 50 psia and is operating in automatic pressure control, the tunnel Controller will not allow pressure inputs above 50 psia. If the user is operating in automatic Reynolds number control, the user again will not be able to exceed the set Reynolds number limit. If the user is operating in manual \( \text{GN}_2 \) exhaust valve control, the pressure can exceed the 50 psia limit but not the tunnel pressure limit of 88 psia.

Because the Reynolds number control is obtained through pressure control, the Reynolds number will be restricted by the pressure limit of 50 psia and, therefore limits the Reynolds number even though a user set limit for Reynolds number is not set. This Reynolds number limitation can be easily overcome by lowering the tunnel gas temperature.

**Display of Input Limits**

With the ability of the user to set the tunnel operating limits the user needs to know these limits. These limits are now displayed in the bottom two rows of the Controller display screen in the section titled **LIMITS** as shown in figure 2. The limit ranges for each variable are displayed within their corresponding control loop columns.

**Improve Screen Layout**

The Controller display layout shown in figure 2 is nearly identical to the original Controller except for **LIMITS** displayed at the bottom two rows of the screen. Improvements have been made in color and spacing for the visual warnings for an "Emergency Stop". Also, displays are now centered in their perspective control loop columns.

The Reynolds number display has been changed to allow Reynolds numbers of over 99 million. Before, when the Reynolds number reached 100 million, the display showed a % symbol indicating a display overflow.

The RPM/MACH LOOP now clears the old set point when changing from manual to automatic control. The Pt/Re LOOP also clears the old set point when changing from automatic pressure control to automatic Reynolds number control.
Aerodynamic Chord Input

In the original Controller chord length input was in meters. This has been changed so that the chord input is now in inches. This change has been made to improve ease of use for the Controller.

Tunnel Operating Envelope Safety Catches

Included in the Controller are safety catches which will safely stop the tunnel by an "Emergency Stop" if the tunnel limits for pressure or normal fan speed are exceeded. In the original Controller it was possible to over pressurize the tunnel when operating with manual GN exhaust valve control. These safety catches are additional safety features which are duplicated in several other tunnel safety devices separate from the Controller.

Identify Causes of an Emergency Stop

The Controller "Emergency Stop" procedure brings the tunnel to a safe condition. The original Controller displayed only "Emergency Stop" and if the problem was a sensor failure, "Sensor Failure" was also displayed. This was frustrating for the user not knowing what had caused the "Emergency Stop". This "Emergency Stop" condition now displays the cause of the "Emergency Stop" and identifies the failed sensor during a "Sensor Failure". Causes of an "Emergency Stop" are displayed as "Pressure Limit", "Fan RPM Limit", or "Sensor Failure". During a "Sensor Failure" the failed sensors are identified as "Gas Temperature", "Wall Temperature", "Total Pressure", "Static Pressure", and "Screen Pressure". These displays will allow the 0.3-m TCT staff to correct tunnel problems quickly.

Improved Organization of Source Code

The source code has now been divided into logical sections which pertain to certain functions of the Controller. These divisions are designed to allow for an easier understanding of the source code. Some sections have been rearranged to reduce the number of lines and improve the Controller execution times.
Improved Cooldown Efficiency

The automatic cooldown of the Controller is one of its best features. It allows for a safe, automatic, and efficient cooldown of the tunnel to any desired temperature set point. The temperature control loop achieves this cooldown by using a "use" temperature set point which is based on an acceptable temperature difference between the tunnel wall and gas.

During tunnel operations the temperature set point is changed frequently by the user and the Controller always uses the previous cycle "use" temperature set point as a starting point to reach the desired temperature set point. This works well until the tunnel is already cool and a user chooses a warmer temperature set point and then changes back to a cold temperature set point. Because the Controller uses the previous cycle "use" temperature set point to start cooling, it can take several cycles before the "use" temperature set point reaches the actual tunnel gas temperature. This provides a period during a cooldown in which the tunnel is actually warming up waiting for the "use" temperature set point to reach the actual tunnel gas temperature.

This problem has been corrected by setting the "use" temperature set point previous cycle value, STP, to the tunnel gas temperature, TT. This occurs only during a new temperature input to cooldown the tunnel.

Improved "On" Set Point Flags

The "On" set point flags are black bands which are shown when the tunnel is within a given tolerance of a desired set point. These "On" set point flags work well to indicate quickly and easily when the tunnel had reached a desired condition. However, there was confusion about the temperature and Reynolds number "On" set point flags.

In the original Controller the temperature "On" set point flag was displayed when the absolute difference between the gas temperature, TT, and the "use" temperature set point, ST, was less then or equal to 0.3. This condition for displaying the "On" set point flag allowed the flag to be displayed when the tunnel was not near the desired temperature set point, ST1. This caused some confusion in determining if the tunnel was actually "On" temperature set point. To remove this confusion the "On" set point flag for temperature is now displayed when the absolute difference between the tunnel temperature, TT, and the desired temperature set point, ST1 is less than or equal to 0.3.
When operating in the Reynolds number control loop the user chooses a desired Reynolds number and a pressure is calculated to give this desired Reynolds number. The confusion occurs because Reynolds number control is still through the pressure control loop. The "On" set point flag in the original Controller is for pressure only. This can cause the "On" set point flag to be "On" when in the Reynolds number control loop while there is still a large difference between the desired Reynolds number set point, \( S_{RE} \), and the tunnel Reynolds number, \( R_{E} \). The solution to eliminate this confusion was to make a separate condition for the "On" set point flag for use when in the Reynolds number control loop. This has been accomplished by the addition of the logic flag \( FL7 \). The Reynolds number "On" set point flag is now displayed when the difference between the desired Reynolds number set point, \( S_{RE} \), and the tunnel Reynolds number, \( R_{E} \), is less than or equal to 0.05.

The controller now has "On" set point flags which display when the conditions of the tunnel are those of the desired user set points.

**Rewrite Source Code**

The original source code was written in the BASIC language which requires a line number for every line of code used in the program. This line numbering causes some difficulty when trying to add to the program. The source code has been rewritten and compiled using MicroSoft QuickBASIC (Ref. 3). The advantages of using QuickBASIC are that it does not require line numbers for each line of code and all statements are identical to the original source code. Line numbers in QuickBASIC are only required on lines which are called by other lines. This lack of line numbers makes additions or changes much simpler. QuickBASIC also has a BASIC compiler that provides a faster compiled Controller program. The source code listings in Appendix A and B are in QuickBASIC.
### 0.3-m TUNNEL T-P/R-M CONTROLLER

<table>
<thead>
<tr>
<th>SET POINT</th>
<th>LN PUMP AUTO</th>
<th>TEMP LOOP AUTO</th>
<th>Pt/Re LOOP AUTOP</th>
<th>RPM/MACH LOOP AUTO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>132.3,psia</td>
<td>200.0,K(Final)</td>
<td>45.00,Psia</td>
<td>0.765,Mach</td>
</tr>
<tr>
<td></td>
<td></td>
<td>200.0,K(Use)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PROCESS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>132.3,psia</td>
<td>200.0,K-GN2</td>
<td>45.00,Psia</td>
<td>0.765,Mach</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>200.5,K-WALL</td>
<td>12.79,Miln</td>
<td>4165.,RPM</td>
</tr>
<tr>
<td>COMMAND</td>
<td>69.6,%opn</td>
<td>20.1,%opn</td>
<td>36.0,%opn V1</td>
<td>55.5,% Rhst</td>
</tr>
<tr>
<td></td>
<td>20.1,%opn</td>
<td>20.1,%opn</td>
<td>0.0,%opn V2</td>
<td></td>
</tr>
<tr>
<td>INPUTS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delete</td>
<td>Temp=</td>
<td>Pres=</td>
<td>Mach=</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ALQ%=</td>
<td>Ryno=</td>
<td>Nrpm=</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>AGv%=</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chrd=</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STATUS</td>
<td>GRAD= 0.0,K/mt</td>
<td>CHORD= 7.09,in</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SAT= 93.8,K</td>
<td>P st= 30.54,psia</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Del P= 0.000,psi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LIMITS</td>
<td>77 &lt; T &lt; 340</td>
<td>14.7 &lt; P &lt; 88.0</td>
<td>0 &lt; N &lt; 5600</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.0 &lt; R &lt; 50.0</td>
<td>0.15 &lt; M &lt; 0.995</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. Typical Controller Display.
<table>
<thead>
<tr>
<th></th>
<th>Tunnel Maximum</th>
<th>Set Maximum</th>
<th>Set Minimum</th>
<th>Tunnel Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (kelvin)</td>
<td>340.0</td>
<td>340.0</td>
<td>&lt; T &lt;</td>
<td></td>
</tr>
<tr>
<td>Pressure (psia)</td>
<td>88.00</td>
<td>&lt; P &lt;</td>
<td>14.70</td>
<td>Ambient Pressure</td>
</tr>
<tr>
<td>Normal Fan Speed (rpm)</td>
<td>5600.</td>
<td>&lt; N &lt;</td>
<td>0.</td>
<td>0.</td>
</tr>
<tr>
<td>Mach Number</td>
<td>0.995</td>
<td>&lt; M &lt;</td>
<td>0.150</td>
<td>0.150</td>
</tr>
<tr>
<td>Reynolds Number (Mln)</td>
<td>50.00</td>
<td>&lt; R &lt;</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Accept Tunnel Max./Min. Limits and Start 0.3-m TCT Controller.
Accept Set Max./Min. Limits and Start 0.3-m TCT Controller.

Figure 1. Maximum - Minimum Limits Display.
References


Appendix A
Controller Source Code Listing

'0.3-m Transonic Cryogenic Tunnel Controller.
CLS
CLEAR

'Set up of the Digital to Analog Converter.
DEFINT I, Z
DIM E(8), DAC(8)
ZASE.ADDRESS = &H2EC
ZOMMAND.REGISTER = ZASE.ADDRESS + 1
ZSTATUS.REGISTER = ZASE.ADDRESS + 1
ZATA.REGISTER = ZASE.ADDRESS
ZOMMAND.WAIT = &H14
WRITE.WAIT = &H12
READ.WAIT = &H15
ZERROR = &H12
ZCLEAR = &H11
ZADIN = &H1C
ZSTOP = &H1F

'Digital to Analog Conversion Board Test.
OUT &H225, 0
FOR JJ = 1 TO 300
BSL = SQR(7)
NEXT JJ
AEMP = INP(&H225)
IF AEMP = 4 THEN 2
PRINT "Digital to Analog Conversion Problem!": PRINT
GOTO 10000
2 OUT &H224, &H6

'Program Constants.
DEI = .1
CGV = 8
CI = .18
CHN = .18 * .0245
CLOV = 4
IW = 39
K = 1
KDL = 0!
KDP = 0!
KDT = 0!
KIL = .02
KIM = 0!
KIN = .4
KIP = .05
KIT = .1
KMM = .3
KP = .3
KPL = .2
KPM = 4.5
KPN = .6
KPP = 1!
KPT = 1!
KT = .04
MXT = 40
S1QSC = 17
STP = 300!
XDLP = 1!
XPTRP = 12811
XPIQ = 5.103429
XPP = 1.366
XPS = 1.366

'Maximum - Minimum Limits Screen Layout.
COLOR 14, 9
CLS
LOCATE 3, 16: PRINT " Maximum - Minimum Limits for 0.3-m TCT Controller "

COLOR 12, 9
LOCATE 5, 25: PRINT "Tunnel"
LOCATE 6, 24: PRINT "Maximum"
LOCATE 5, 38: PRINT "Set"
LOCATE 6, 36: PRINT "Maximum"
LOCATE 5, 60: PRINT "Set"
LOCATE 6, 58: PRINT "Minimum"
LOCATE 5, 72: PRINT "Tunnel"
LOCATE 6, 71: PRINT "Minimum"

COLOR 7, 9
LOCATE 7, 3: PRINT "Temperature"
LOCATE 8, 4: PRINT "(kelvin)"
LOCATE 10, 3: PRINT "Pressure"
LOCATE 11, 4: PRINT "(psia)"
LOCATE 13, 3: PRINT "Normal Fan Speed"
LOCATE 14, 4: PRINT "(rpm)"
LOCATE 16, 3: PRINT "Mach Number"
LOCATE 19, 3: PRINT "Reynolds Number"
LOCATE 20, 4: PRINT "(Mln)"
LOCATE 22, 3: PRINT "Accept Tunnel Max./Min. Limits and Start 0.3-m TCT Controller." LOCATE 23, 3: PRINT "Accept Set Max./Min. Limits and Start 0.3-m TCT Controller."

COLOR 15, 9
LOCATE 7, 51: PRINT "I"
LOCATE 7, 49: PRINT CHR$(243)
LOCATE 7, 53: PRINT CHR$(243)
LOCATE 10, 51: PRINT "P"
LOCATE 10, 49: PRINT CHR$(243)
LOCATE 10, 53: PRINT CHR$(243)
LOCATE 13, 51: PRINT "N"
LOCATE 13, 49: PRINT CHR$(243)
LOCATE 13, 53: PRINT CHR$(243)
LOCATE 16, 51: PRINT "M"
LOCATE 16, 49: PRINT CHR$(243)
LOCATE 16, 53: PRINT CHR$(243)
LOCATE 19, 51: PRINT "R"
LOCATE 19, 49: PRINT CHR$(243)
LOCATE 19, 53: PRINT CHR$(243)

COLOR 14, 9
LOCATE 7, 3: PRINT "I"
LOCATE 10, 3: PRINT "P"
LOCATE 13, 3: PRINT "N"
LOCATE 16, 3: PRINT "M"
LOCATE 19, 3: PRINT "R"
LOCATE 22, 3: PRINT "A"
LOCATE 23, 10: PRINT "S"

*Tunnel Maximum-Minimum Limits.*
MAXTI = 340!
MINTI = 77!
MAXP1 = 88!
MINP1 = 14.696
MAXN1 = 5600!
MINN1 = 0!
MAXM1 = .995
MINM1 = .15
MAXRE1 = 50!
MINRE1 = 1!
MAXCI1N = 15.75
MINCI1N = .394
MAXCI1 = .4
MINCI1 = .01
MAXLQSC = 150!
MAXSPR = MAXP1 / 14.696
MINSPR = MINP1 / 14.696

MAXT = MAXTI
MIINT = MINTI
MAXP = MAXP1
MINP = MINP1
MAXN = MAXN1
MINN = MINN1
MAXM = MAXM1
MINM = MINM1
MAXRE = MAXRE1
MINRE = MINRE1

COLOR 10, 9
LOCATE 7, 25: PRINT USING "###.#"; MAXTI
LOCATE 7, 37: PRINT USING "###.#"; MAXTI
LOCATE 10, 25: PRINT USING "#####"; MAXP1
LOCATE 10, 59: PRINT USING "#####"; MINP1
LOCATE 13, 25: PRINT USING "#####"; MAXN1
LOCATE 13, 60: PRINT USING "#####"; MINN1
LOCATE 16, 25: PRINT USING "#####"; MAXM1
LOCATE 16, 60: PRINT USING "#####"; MINM1
LOCATE 19, 25: PRINT USING "#####"; MAXRE1
LOCATE 19, 60: PRINT USING "#####"; MINRE1
LOCATE 7, 69: PRINT "Saturation"
LOCATE 8, 69: PRINT "Temperature"
LOCATE 10, 71: PRINT "Ambient"
LOCATE 11, 71: PRINT "Pressure"
LOCATE 13, 73: PRINT USING "#####", MINN1
LOCATE 16, 73: PRINT USING "#####", MINM1
LOCATE 19, 73: PRINT USING "#####", MINRE1

12
'Maximum - Minimum Limits Inputs.

5 AS = INKEY$
    IF AS = "T" OR AS = "t" THEN GOSUB 10
    IF AS = "P" OR AS = "p" THEN GOSUB 100
    IF AS = "N" OR AS = "n" THEN GOSUB 200
    IF AS = "M" OR AS = "m" THEN GOSUB 300
    IF AS = "R" OR AS = "r" THEN GOSUB 400
    IF AS = "A" OR AS = "a" THEN 500
    IF AS = "S" OR AS = "s" THEN 600
    GOTO 5

'Temperature Minimum Limit Subroutine.

10 COLOR 15, 9
    BEEP
    LR = 7
    LC = 58
    LOCATE LR, LC + 1: PRINT "K"
    XX = 0
20 BS = INKEY$
    IF BS = "D" OR BS = "d" THEN 30 ELSE 40
30 LOCATE LR, LC + 1: PRINT "K"
    RETURN
40 IF BS = "0" OR BS = "1" OR BS = "2" OR BS = "3" OR BS = "4" OR BS = "5" OR BS = 
    "6" OR BS = "7" OR BS = "8" OR BS = "9" OR BS = "." THEN 50 ELSE 20
50 XX = XX + 1
    IF XX = 1 THEN H1 = VAL(B$): LOCATE LR, LC + 1: PRINT USING ";H"; H1
    IF XX = 2 THEN H2 = VAL(B$): LOCATE LR, LC + 2: PRINT USING ";H"; H2
    IF XX = 3 THEN H3 = VAL(B$): LOCATE LR, LC + 3: PRINT USING ";H"; H3
    IF XX = 4 THEN LOCATE LR, LC + 4: PRINT CHR$(46)
    IF XX = 5 THEN H5 = VAL(B$): LOCATE LR, LC + 5: PRINT USING ";H"; H5
    IF XX = 5 THEN 60 ELSE 20
60 AA = H1 * 100 + H2 * 10 + H3 + H5 / 10
    MINT = AA
    IF MINT >= MAXT1 THEN MINT = MAXT1
    IF MINT <= MINT1 THEN MINT = MINT1
70 CS = INKEY$
    IF CS = CHR$(13) THEN 80 ELSE 70
80 BEEP
    COLOR 14, 9
    LOCATE LR, LC + 1: PRINT USING ";###.# "; MINT
    RETURN

'Pressure Maximum Limit Subroutine.

100 COLOR 15, 9
    BEEP
    LC = 36
    LR = 10
    LOCATE LR, LC + 1: PRINT "psia"
    XX = 0
110 BS = INKEY$
    IF BS = "D" OR BS = "d" THEN 120 ELSE 130
120 LOCATE LR, LC + 1: PRINT "psia"
    RETURN
    IF BS = "0" OR BS = "1" OR BS = "2" OR BS = "3" OR BS = "4" OR BS = "5" OR BS = 
    "6" OR BS = "7" OR BS = "8" OR BS = "9" OR BS = "." THEN 140 ELSE 110
140 XX = XX + 1
IF XX = 1 THEN H1 = VAL(B$): LOCATE LR, LC + 1: PRINT USING "#": H1
IF XX = 2 THEN H2 = VAL(B$): LOCATE LR, LC + 2: PRINT USING "#": H2
IF XX = 4 THEN H3 = VAL(B$): LOCATE LR, LC + 4: PRINT USING "#": H3
IF XX = 3 THEN LOCATE LR, LC + 3: PRINT CHRS(46)
IF XX = 5 THEN H5 = VAL(B$): LOCATE LR, LC + 5: PRINT USING "#": H5
IF XX = 5 THEN 150 ELSE 110
150 AA = H1 * 10 + H2 + H3 / 10 + H5 / 100
MAXP = AA
IF MAXP <= MINP THEN 160 ELSE 170
160 MAXP = MINP
COLOR 20, 8: LOCATE LR + 1, 36: PRINT " Warning! Set Max. = Tunnel Min. "
FL0 = 1
GOTO 180
170 COLOR 14, 9: LOCATE LR + 1, 36: PRINT "
FL0 = 0
180 CS = INKEYS
IF CS = CHR$(13) THEN 195 ELSE 190
190 BEEP
COLOR 14, 9
LOCATE LR, LC + 1: PRINT USING "##.##": MAXP
RETURN
*Normal Fan Speed Maximum Limit Subroutine.
200 COLOR 15, 9
BEEP
LC = 36
LR = 13
LOCATE LR, LC + 1: PRINT " rpm"
XX = 0
210 B$ = INKEYS
IF B$ = "D" OR B$ = "d" THEN 220 ELSE 230
220 LOCATE LR, LC + 1: PRINT "
RETURN
230 IF B$ = "0" OR B$ = "1" OR B$ = "2" OR B$ = "3" OR B$ = "4" OR B$ = "5" OR B$ = "6" OR B$ = "7" OR B$ = "8" OR B$ = "9" OR B$ = "." THEN 240 ELSE 210
240 XX = XX + 1
IF XX = 1 THEN H1 = VAL(B$): LOCATE LR, LC + 1: PRINT USING ";": H1
IF XX = 2 THEN H2 = VAL(B$): LOCATE LR, LC + 2: PRINT USING ";": H2
IF XX = 3 THEN H3 = VAL(B$): LOCATE LR, LC + 3: PRINT USING ";": H3
IF XX = 5 THEN LOCATE LR, LC + 5: PRINT CHRS(46)
IF XX = 4 THEN H5 = VAL(B$): LOCATE LR, LC + 4: PRINT USING ";": H5
IF XX = 5 THEN 250 ELSE 210
250 AA = H1 * 1000 + H2 * 100 + H3 * 10 + H5
MAXN = AA
IF MAXN <= MINN THEN 260 ELSE 270
260 MAXN = MINN
COLOR 20, 8: LOCATE LR + 1, 36: PRINT " Warning! Set Max. = Tunnel Min. "
FL0 = 1
GOTO 280
270 COLOR 14, 9: LOCATE LR + 1, 36: PRINT "
FL0 = 0
280 CS = INKEYS
IF CS = CHR$(13) THEN 295 ELSE 290
290 BEEP
COLOR 14, 9
300  COLOR 15, 9
    BEEP
    LC = 36
    LR = 16
    LOCATE LR, LC + 1: PRINT "Mach";
    XX = 0
310  BS = INKEY$  
    IF BS = "D" OR BS = "d" THEN 320 ELSE 330
320  LOCATE LR, LC + 1: PRINT "*
    RETURN
330  IF BS = "0" OR BS = "1" OR BS = "2" OR BS = "3" OR BS = "4" OR BS = "5" OR BS = "6" OR BS = "7" OR BS = "8" OR BS = "9" OR BS = "." THEN 340 ELSE 310
340  XX = XX + 1
    IF XX = 1 THEN H_1 = VAL(B$): LOCATE LR, LC + 1: PRINT USING "#"; H1
    IF XX = 3 THEN H_2 = VAL(B$): LOCATE LR, LC + 3: PRINT USING "#"; H2
    IF XX = 4 THEN H_3 = VAL(B$): LOCATE LR, LC + 4: PRINT USING "#"; H3
    IF XX = 2 THEN LOCATE LR, LC + 2: PRINT CHR$(46)
    IF XX = 5 THEN H_5 = VAL(B$): LOCATE LR, LC + 5: PRINT USING "#"; H5
    IF XX = 5 THEN 350 ELSE 310
350  AA = H_1 + H_2 / 10 + H_3 / 100 + H_5 / 1000
    MAXM = AA
    IF MAXM <= MINM THEN 360 ELSE 370
360  MAXM = MINM
    COLOR 20, 8: LOCATE LR + 1, 36: PRINT "Warning! Set Max. = Tunnel Min."
    FLO = 1
    GOTO 380
370  COLOR 14, 9: LOCATE LR + 1, 36: PRINT "*
    FLO = 0
380  IF MAXM > MAXM THEN MAXM = MAXM
390  CS = INKEY$  
    IF CS = CHR$(13) THEN 395 ELSE 390
395  BEEP  
    COLOR 14, 9
    LOCATE LR, LC + 1: PRINT USING "####. "; MAXM
    RETURN

400  COLOR 15, 9
    BEEP
    LC = 36
    LR = 19
    LOCATE LR, LC + 1: PRINT "Min";
    XX = 0
410  BS = INKEY$  
    IF BS = "D" OR BS = "d" THEN 420 ELSE 430
420  LOCATE LR, LC + 1: PRINT "*
    RETURN
430  IF BS = "0" OR BS = "1" OR BS = "2" OR BS = "3" OR BS = "4" OR BS = "5" OR BS = "6" OR BS = "7" OR BS = "8" OR BS = "9" OR BS = "." THEN 440 ELSE 410
440  XX = XX + 1
    IF XX = 1 THEN H_1 = VAL(B$): LOCATE LR, LC + 1: PRINT USING "#"; H1
    IF XX = 2 THEN H_2 = VAL(B$): LOCATE LR, LC + 2: PRINT USING "#"; H2
IF XX = 4 THEN H3 = VAL(B$): LOCATE LR, LC + 4: PRINT USING "#"; H3
IF XX = 3 THEN LOCATE LR, LC + 3: PRINT CHR$(46)
IF XX = 5 THEN H5 = VAL(B$): LOCATE LR, LC + 5: PRINT USING "#"; H5
IF XX = 5 THEN 450 ELSE 410

450 AA = H1 * 10 + H2 + H3 / 10 + H5 / 100
MAXRE = AA
IF MAXRE <= MINRE1 THEN 460 ELSE 470

460 MAXRE = MINRE1
COLOR 20, 8: LOCATE LR + 1, 36: PRINT " Warning! Set Max. = Tunnel Min. "
FLR = 1
GOTO 480

470 COLOR 14, 9: LOCATE LR + 1, 36: PRINT " 
FLR = 0

480 CS = INKEY$
IF CS = CHR$(13) THEN 495 ELSE 490

495 HEEP
COLOR 14, 9
LOCATE LR, LC + 1: PRINT USING "###.### "; MAXRE
RETURN

'Starts the 0.3-m TCT Controller with Tunnel Maximum - Minimum Limits.
500 XX = 0
GOTO 800

'Starts the 0.3-m TCT Controller with Set Maximum - Minimum Limits.
600 IF FLR = 1 THEN GOTO 5
XX = 0
MAXSPR = MAXP / 14.696
MINSPR = MINP / 14.696
GOTO 800

'0.3-m TCT T-P/Re-M Controller Program.

'Controller Screen Layout.
800 COLOR 0, 0
CLS
COLOR 15, 4
LOCATE 1, 26: PRINT " 0.3-m TUNNEL T-P/R-M CONTROLLER ">

FOR I = 2 TO 25
COLOR 15, 1
LOCATE I, 2: PRINT STRINGS$(10, 0):
  IF I = 4 THEN LOCATE 4, 2: PRINT STRINGS$(10, 205):
  IF I = 14 THEN LOCATE 14, 2: PRINT STRINGS$(10, 205):
  IF I = 19 THEN LOCATE 19, 2: PRINT STRINGS$(10, 205):
  IF I = 23 THEN LOCATE 23, 2: PRINT STRINGS$(18, 205):
COLOR 15, 2
LOCATE I, 12: PRINT STRINGS$(12, 0):
  IF I = 4 THEN LOCATE 4, 12: PRINT STRINGS$(12, 205):
  IF I = 14 THEN LOCATE 14, 12: PRINT STRINGS$(12, 205):
  IF I = 19 THEN LOCATE 19, 12: PRINT STRINGS$(12, 205):
  IF I = 23 THEN LOCATE 23, 12: PRINT STRINGS$(18, 205):
COLOR 15, 3
LOCATE I, 24: PRINT STRINGS$(17, 0);
IF I = 4 THEN LOCATE 4, 24: PRINT STRINGS(17, 205);
IF I = 14 THEN LOCATE 14, 24: PRINT STRINGS(17, 205);
IF I = 19 THEN LOCATE 19, 24: PRINT STRINGS(17, 205);
IF I = 23 THEN LOCATE 23, 24: PRINT STRINGS(18, 205);
COLOR 15, 5
LOCATE 1, 41: PRINT STRINGS$(18, 0);
IF I = 4 THEN LOCATE 4, 41: PRINT STRINGS$(18, 205);
IF I = 14 THEN LOCATE 14, 41: PRINT STRINGS$(18, 205);
IF I = 19 THEN LOCATE 19, 41: PRINT STRINGS$(18, 205);
IF I = 23 THEN LOCATE 23, 41: PRINT STRINGS$(18, 205);
COLOR 15, 6
LOCATE 1, 59: PRINT STRINGS$(18, 0);
IF I = 4 THEN LOCATE 4, 59: PRINT STRINGS$(18, 205);
IF I = 14 THEN LOCATE 14, 59: PRINT STRINGS$(18, 205);
IF I = 19 THEN LOCATE 19, 59: PRINT STRINGS$(18, 205);
IF I = 23 THEN LOCATE 23, 59: PRINT STRINGS$(18, 205);
NEXT I
COLOR 15, 2
LOCATE 2, 14: PRINT " LN PUMP ": PRINT ;
LOCATE 3, 14: PRINT " AUTO ": PRINT ;
LOCATE 5, 18: PRINT ", psi": PRINT ;
LOCATE 9, 18: PRINT ", psi": PRINT ;
LOCATE 12, 18: PRINT ", %opn": PRINT ;
LOCATE 15, 12: PRINT " = ": PRINT ;
LOCATE 5, 13: PRINT USING ",###,###", SLQSC
COLOR 14, 2
LOCATE 15, 12: PRINT "I": PRINT ;
COLOR 15, 3
LOCATE 2, 28: PRINT " TEMP LOOP": PRINT ;
LOCATE 3, 29: PRINT " MANUAL ": PRINT ;
LOCATE 5, 31: PRINT ", K(\text{Final})": PRINT ;
LOCATE 6, 31: PRINT ", K(\text{Use})": PRINT ;
LOCATE 9, 31: PRINT ", K-GN2": PRINT ;
LOCATE 10, 31: PRINT ", K-WALL": PRINT ;
LOCATE 12, 31: PRINT ", %opn": PRINT ;
LOCATE 15, 25: PRINT " cmp = ": PRINT ;
LOCATE 16, 25: PRINT " A Q\% = ": PRINT ;
LOCATE 20, 25: PRINT " GRAD = K/m\text{t}": PRINT ;
LOCATE 21, 25: PRINT " SAT = \text{K}": PRINT ;
LOCATE 24, 32: PRINT " T";
LOCATE 24, 30: PRINT CHR$(243);
LOCATE 24, 34: PRINT CHR$(243);
LOCATE 24, 26: PRINT USING "###": MINT;
LOCATE 24, 36: PRINT USING "###": MAXT;
COLOR 14, 3
LOCATE 15, 25: PRINT " T": PRINT ;
LOCATE 16, 26: PRINT " L": PRINT ;
COLOR 15, 5
LOCATE 2, 45: PRINT " Pr/Re LOOP": PRINT ;
LOCATE 3, 46: PRINT " MANUAL ": PRINT ;
LOCATE 5, 48: PRINT ",Psia": PRINT ;
LOCATE 6, 48: PRINT ",Min": PRINT ;
LOCATE 20, 42: PRINT "CIORD= 7.09,in": PRINT ;
LOCATE 9, 48: PRINT ",Psia": PRINT ;
LOCATE 21, 42: PRINT "P st= ,psia": PRINT ;
LOCATE 22, 42: PRINT "Dei P= ,psi": PRINT ;
LOCATE 10, 48: PRINT ",Min": PRINT ;
LOCATE 12, 48: PRINT ",%open V1": PRINT ;
LOCATE 13, 48: PRINT ",%open V2": PRINT ;
LOCATE 15, 43: PRINT " res=": PRINT ;
LOCATE 16, 43: PRINT " yno=": PRINT ;
LOCATE 17, 43: PRINT "A v%=": PRINT ;
LOCATE 18, 43: PRINT " hr=": PRINT ;
LOCATE 24, 50: PRINT ",P"
LOCATE 24, 52: PRINT CHR$(243);
LOCATE 24, 43: PRINT USING "##.#": MINP;
LOCATE 24, 54: PRINT USING "##.#": MAXP;
LOCATE 25, 50: PRINT ",R"
LOCATE 25, 48: PRINT CHR$(243);
LOCATE 25, 52: PRINT CHR$(243);
LOCATE 25, 43: PRINT USING "##.#": MINRE;
LOCATE 25, 54: PRINT USING "##.#": MAXRE;
COLOR 14, 5
LOCATE 15, 43: PRINT "P": PRINT ;
LOCATE 16, 43: PRINT "R": PRINT ;
LOCATE 17, 44: PRINT "G": PRINT ;
LOCATE 18, 43: PRINT "C": PRINT ;
COLOR 15, 6
LOCATE 2, 62: PRINT "RPM/MACH LOOP": PRINT
LOCATE 3, 64: PRINT " MANUAL ": PRINT ;
LOCATE 5, 67: PRINT ",Mach": PRINT ;
LOCATE 6, 67: PRINT "RPM": PRINT ;
LOCATE 9, 67: PRINT ",Mach": PRINT ;
LOCATE 10, 67: PRINT "RPM": PRINT ;
LOCATE 12, 67: PRINT ",% RhsT": PRINT ;
LOCATE 15, 61: PRINT ", ach=": PRINT ;
LOCATE 16, 61: PRINT ", rpm=": PRINT ;
LOCATE 24, 68: PRINT "N"
LOCATE 24, 66: PRINT CHR$(243);
LOCATE 24, 70: PRINT CHR$(243);
LOCATE 24, 61: PRINT USING "####": MINN;
LOCATE 24, 72: PRINT USING "####": MAXN;
LOCATE 25, 68: PRINT "M"
LOCATE 25, 66: PRINT CHR$(243);
LOCATE 25, 70: PRINT CHR$(243);
LOCATE 25, 61: PRINT USING ".###": MINM;
LOCATE 25, 72: PRINT USING ".###": MAXM;
COLOR 14, 6
LOCATE 15, 61: PRINT "M": PRINT ;
LOCATE 16, 61: PRINT "N": PRINT ;
COLOR 15, 1
LOCATE 5, 3: PRINT "SET POINT": PRINT ;
LOCATE 9, 3: PRINT "PROCESS": PRINT;
LOCATE 12, 3: PRINT "COMMAND": PRINT;
LOCATE 15, 3: PRINT "INPUTS": PRINT;
LOCATE 20, 3: PRINT "STATUS": PRINT;
LOCATE 16, 3: PRINT "elete": PRINT;
LOCATE 24, 3: PRINT "LIMITS":

COLOR 14, 1
LOCATE 16, 3: PRINT "D": PRINT;

'Controller Program.
1000 GOSUB 8000

'Conversion of Digital Inputs to Engineering Units.
PP = E(1) * XPP
PPUSCS = PP * 14.696
PS = E(2) * XPS
IF PS > (PP * .999999) THEN PS = PP * .999999
PSUSCS = PS * 14.696
IF E(3) > 1.191 THEN 2080 ELSE 2060
2060 TT = 74.1826 + 105.3 * E(3) - 40.66 * E(3) * 2 + 20.54 * E(3) ^ 3 - 5.21 * E(3) ^ 4
GOTO 2090
2080 TT = 80.678 + 84.52 * E(3) - 12.717 * E(3) ^ 2 + 1.805 * E(3) ^ 3 - 1.102 * E(3) ^ 4
GOTO 2100
2090 IF E(4) > 1.191 THEN 2120 ELSE 2100
2100 TMWL = 74.183 + 105.3 * E(4) - 40.66 * E(4) * 2 + 20.54 * E(4) ^ 3 - 5.21 * E(4) ^ 4
GOTO 2130
2120 TMWL = 80.678 + 84.52 * E(4) - 12.717 * E(4) * 2 + 1.805 * E(4) ^ 3 - 1.102 * E(4) ^ 4
2130 FRPM = E(5) * XFRPM
PLQ = E(6) * XPLQ
PLQUSCS = PLQ * 14.696
DLP = E(7) * XDLP

GOSUB 5000

M = SQR(5 * (PP / PS) ^ .28571 - 5)
MF = (1 + .2 * M * M)
KRE = 63714 * CIH * M / TT ^ 1.4 / (MF) ^ 2.1
RE = KRE * PP
SAT = 50 + 27.34 * PS ^ .256
SAT1 = SAT * MF
LDPQ = (PLQ - PP)
IF LDPQ < .5 THEN LDPQ = .5
LF = CLQV * .8676 * SQR(LDPQ)
DRPM = FRPM
IF DRPM < 100 THEN DRPM = 100
KTGS = DRPM * SQR(PP) * KT / 3! / TT / LF
TTMP = TT
IF TTMP < 80 THEN TTMP = 80
FKW = 100 * PP * (FRPM / 1000) ^ 2.26 / SQR(TTMP)
FB = FKW / (121 + TT) / LF
SPR = SP / 14.696
SPR1 = SPR * SRE / KRE
IF SPR1 > MAXSPR THEN SPR1 = MAXSPR
IF SPR1 < MINSPR THEN SPR1 = MINSPR
IF AUTORE = 1 THEN SPR = SPR1
SPRU = SPR * 14.696
COLOR 14, 5
IF AUTORE = 1 THEN LOCATE 5, 43: PRINT USING "##.##"; SPRU

'Temperature Control Loop.
IF IE = 1 THEN 2950
IF (TMWL - T') > 1.5 * MXT THEN 2950
IF FRPM < 580 THEN 2950
ST = ST1
IF ST > TT THEN 2530 ELSE 2525
2525 IF ST < (STP - .04) THEN ST = (STP - .04)
2530 IF AUTOT = 1 THEN 2540 ELSE 2850
2540 IF AUTOP = 0 THEN 2610
2560 IF ABS(PP - SPR) < .15 THEN 2560 ELSE 2570
2570 IF (PP / T') > .95 * (SPR / ST) THEN 2610 ELSE 2580
2580 IF TT > ST THEN 2610 ELSE 2590
2590 ST = TT - .02
2610 IF (TMWL - ST - MXT) > 0 THEN 2620 ELSE 2650
2620 ST = TMWL - MXT
FB = 0
2650 IF ST < SAT1 THEN ST = SAT1
ET = TT - ST
IF ABS(ET) < .3 THEN HI.1 = 1 ELSE HI.1 = 0
IF ABS(TMWL - T') < 4 THEN FL.2 = 1 ELSE FL.2 = 0
IF ET < -5 THEN FF = 0
IF ET > 0 THEN FF = 1
FBF = FB * FF * .8
RIT = RTM1 + KTP * KTGS * DEL * ET
IF RIT < -FBF THEN RIT = -FBF
IF RIT > (1 - FBF) THEN RIT = (1 - FBF)
IF (TMWL - TT) > MXT / 2 THEN 2750 ELSE 2780
2750 LMT = 1 - (TMWL - TT - MXT / 2) * 2 / MXT
IF LMT < 1 / LF THEN LMT = 1 / LF
IF RIT > LMT THEN RIT = LMT
2780 ALQ = KTGS * (KPT * ET + KDT * (ET - 2 * ETM1 + ETM2) / 2 / DEL) + RIT + FBF
IF ALQ < 0 THEN ALQ = 0
IF ALQ > 1 THEN ALQ = 1
IF (TMWL - TT) > MXT / 2 THEN 2820 ELSE 2830
2820 IF ALQ > LMT THEN ALQ = LMT
2830 LCMDS = ALQ * 100
GOTO 2970
2850 IF LCMDS > 100 THEN LCMDS = 100
ALQ = LCMDS / 100
IF (TMWL - TT) > MXT / 2 THEN 2880 ELSE 2910
2880 LMT = 1 - (TMWL - TT - MXT / 2) * 2 / MXT
IF LMT < 1 / LF THEN LMT = 1 / LF
IF ALQ > LMT THEN ALQ = LMT
2910 RIT = ALQ
GOTO 2970
2950 ALQ = 0
LCMDS = 0
2970 IF ALQ > ALQP + .01 THEN ALQ = ALQP + .01
DAC(1) = ALQ
DAC(2) = ALQ

'Pressure - Reynolds Number Control Loop.
KPGS = 750 * KP / PP / SQR(T')
GF1 = 2.725 * CGV * PP / SQR(T')
IF PPUSCS > MAXP1 THEN PIE = 1: GOSUB 6000
IF IE = 1 THEN 3220
IF ABS(RE - SRE) < .05 THEN FL.7 = 1 ELSE FL.7 = 0
IF AUTOP = 1 THEN 3040 ELSE 3180

3040 EP = PP - SPR
IF ABS(EP) < .005 THEN FL.3 = 1 ELSE FL.3 = 0
RIP = RIPM1 + EP * KPGS * KIP * DEL.
IF RIP < 0 THEN RIP = 0
IF RIP > 1! THEN RIP = 1!
AGV1 = KPGS * (KPP * EP + KDP * (EP - 2 * EPM1 + EPM2) / 2 / DEL) + RIP
IF AGV1 < 0 THEN AGV1 = 0
IF AGV1 > 1! THEN AGV1 = 1!
IF AGV1 > .9 THEN AGV2 = AGV2 + .01
IF AGV1 < .7 THEN AGV2 = AGV2 - .01
IF AGV2 < 0 THEN AGV2 = 0
IF AGV2 > 1! THEN AGV2 = 1!
GCMDS = AGV1 * 100
GOTO 3240

3180 IF GCMDS > 100 THEN GCMDS = 100
RIP = GCMDS / 100
AGV1 = GCMDS / 100
IF FRPM < 500 THEN LCMDS = 0
GOTO 3240

3220 AGV1 = 1!
GCMDS = 100

3240 IF AGV1 < AGVIP - .05 THEN AGV1 = AGVIP - .05
IF AGV1 > AGVIP + .05 THEN AGV1 = AGVIP + .05
DAC(4) = AGV1 * .8 + .2
DAC(5) = AGV2 * .8 + .2

'Fan Speed - Mach Number Control Loop.
IF IE = 1 THEN 3405 ELSE 3410

3405 NCMDS1 = 0
GOTO 3550

3410 NCMDS1 = NCMDS
IF FRPM > MAXN1 THEN NIE = 1: GOSUB 6000
IF AUTOM = 1 THEN 3422 ELSE 3550

3422 IF FRPM < 580 THEN AUTOM = 0: GOTO 3435
FKM = 1 - .5 * M
IF FKM < .71 THEN FKM = .71
KMC = 520 * SQRT(TT) * FKM / PP ^ .035
KMGS = KMC * KMM
IF AIQ > .99 THEN 3432 ELSE 3440

3432 AUTOM = 0
NCMDS = FRPM - 500
IF NCMDS < 0 THEN NCMDS = 0: BEEP

3435 COLOR 14, 6
LOCATE 3, 64: PRINT " \"; NCMDS
LOCATE 6, 62: PRINT USING "####."; NCMDS
GOTO 3550

3440 EM = SM - M
IF ABS(EM) < .002 THEN FL.4 = 1 ELSE FL.4 = 0
RIM = RIMM1 + KIM * EM * DEL * KMGS
IF RIM < -100 THEN RIM = -100
IF RIM > 100 THEN RIM = 100
NCMDS1 = KPM * EM * KMGS + RIM + FRPM
IF NCMDS1 > 5450 THEN NCMDS1 = 5450
IF NCMD51 > MAXN THEN NCMD51 = MAXN

3550   EN = NCMD51 - FRPM
       IF ABS(EN) < 10 THEN FLN = 1 ELSE FLN = 0
       IF ABS(EN) > 100 THEN 3560 ELSE 3570

3560   KEN = 5
       GOTO 3575

3570   KEN = SQRT(TT) / 20

3575   RIN = RINM1 + EN * DEL * KIN
       IF RIN > RINM1 + KEN THEN RIN = RINM1 + KEN
       IF RIN < RINM1 - KEN THEN RIN = RINM1 - KEN
       IF RIN < 0 THEN RIN = 0
       IF RIN > 6000 THEN RIN = 6000

SRPM = EN * KPN + RIN
       IF SRPM > SRPM1 + 5 THEN SRPM = SRPM1 + 5
       IF SRPM < SRPM1 - 5 THEN SRPM = SRPM1 - 5

SNRPM = SRPM / 7500
       IF SNRPM > 1 THEN SNRPM = 1
       IF SNRPM < 0 THEN SNRPM = 0

DAC(6) = SNRPM

'Fan Speed Band Warning.
       IF FRPM < 3651 THEN 3790 ELSE 3830

3790   IF FRPM > 3549 THEN 3800 ELSE 3830

3800   COLOR 20, 8
       LOCATE 13, 61: PRINT "SPEED BAND ": PRINT
       BEEP
       GOTO 3900

3830   COLOR 14, 6
       LOCATE 13, 61: PRINT "": PRINT

'Temperature Gradient Calculation.

3900   IW = IW + 1
       IF IW = 40 THEN 3920 ELSE 3980

3920   IF WLG > 8 THEN WLG = 0
       IF WLG < -8 THEN WLG = 0
       COLOR 14, 3
       LOCATE 20, 30: PRINT USING "###.#"; 12 * WLG
       WLG = 0
       IW = 0

3980   WLG = WLG + TMW1 - TMW1.1

'Liquid Back Pressure Control Loop.

SLQ = SLQSC / 14.696
       IF SLQ > 10.2 THEN SLQ = 10.2

SLQSC = SLQ * 14.696

ELP = PLQ - SLQ
       IF ABS(ELP) < .4 THEN FL.5 = 1 ELSE FL.5 = 0
       IF ELP > .15 THEN ELP = .15
       IF ELP < -.15 THEN ELP = -.15

RIL = RILM1 + ELP * KIL * DEL
       IF RIL < 0 THEN RIL = 0
       IF RIL > 11 THEN RIL = 11

ALN = KPL * ELP + KDL * (ELP - ELPM1) / DEL + RIL
       IF ALN < 0 THEN ALN = 0
       IF ALN > 11 THEN ALN = 11

DAC(3) = ALN
DAC(7) = 1!

GOSUB 9000

'Screen Pressure Drop Warning.

\[ DLPC = 0.47 \cdot PP \cdot M \cdot M / (MI)^6 + 0.02 \]

IF DLPC > DLPC THEN FL6 = 1 ELSE FL6 = 0
IF M < 0.25 THEN FL6 = 0
IF FL6 = 1 THEN BEEP

'Controller Screen Update.

\[ JD = JD + 1 \]
IF JD = 3 THEN 4160 ELSE 4700
4160 COLOR 14, 3
LOCATE 21, 30: PRINT USING "###.#"; SAT1
IF (FL1 * FL2 * AUTOT) = 1 THEN 4190 ELSE 4200
4190 COLOR 14, 0
4200 LOCATE 8, 26: PRINT STRING$(6, 0)
COLOR 14, 5
LOCATE 21, 47: PRINT USING "###.###"; E12 * 20.07474
IF FL6 = 1 THEN COLOR 30, 5
LOCATE 22, 48: PRINT USING "###.###"; DLP
IF AUTORE = 0 THEN 4240
IF (FL7 * AUTORE) = 1 THEN 4250 ELSE 4260
4240 IF (FL1 * AUTORE) = 1 THEN 4240 ELSE 4250
4250 COLOR 14, 0
4260 LOCATE 8, 43: PRINT STRING$(6, 0)
COLOR 14, 2
LOCATE 5, 13: PRINT USING "###.#"; SLQSC
LOCATE 9, 13: PRINT USING "#####"; PLQUSCS
LOCATE 12, 13: PRINT USING "#####"; (1 - ALN) * 100
IF FL5 = 1 THEN 4320 ELSE 4330
4320 COLOR 14, 0
4330 LOCATE 8, 13: PRINT STRING$(6, 0)
COLOR 14, 6
IF (FL4 * AUTOM) = 1 THEN 4360 ELSE 4370
4360 COLOR 14, 0
4370 LOCATE 8, 62: PRINT STRING$(6, 0)
IF (FLN-AUTOM)=0 THEN 4374 ELSE 4376
4374 COLOR 14, 0
4376 LOCATE 11, 62: PRINT STRING$(6, 0)
COLOR 14, 3
IF AUTOT = 1 THEN LOCATE 6, 26: PRINT USING "#####"; ST
LOCATE 9, 26: PRINT USING "#####"; TT
LOCATE 10, 26: PRINT USING "#####"; TMWL
LQ = ALQ * 100
LOCATE 12, 26: PRINT USING "#####"; LQ
COLOR 14, 5
LOCATE 9, 42: PRINT USING "#####"; E11 * 20.07474
GV1 = AGV1 * 100
LOCATE 12, 43: PRINT USING "#####"; GV1
GV2 = AGV2 * 100
LOCATE 13, 43: PRINT USING "#####"; GV2
LOCATE 10, 42: PRINT USING "#####"; RE
COLOR 14, 6
LOCATE 9, 62: PRINT USING "#####"; M
LOCATE 10, 62: PRINT USING "#####"; FRPM
I.OCATE 12, 62: PRINT USING "##.#"; SNRPM * 100
JD = 0

'Setting Previous Cycle Values.
4700 AGVIP = AGV1
ALQP = ALQ
ELPM1 = ELP
EPM2 = EPM1
EPM1 = EP
ETM2 = ETM1
ETM1 = ET
RLIM1 = RIL
RIMM1 = RIM
RINM1 = RIN
RIPM1 = RIP
RITM1 = RIT
SRPM1 = SRPM
STP = ST
TMWI1 = TMW1.

4900 GOTO 1000

'Controller Input Subroutine.
5000 AS = INKEY$
   IF A$ = "" THEN 5999
   IF A$ = "D" OR A$ = "d" THEN 5950
   IF XX > 5 THEN XX = 5
   IF A$ = CHR$(13) THEN 5008 ELSE 5009
5008 IF XX = 5 THEN 5600 ELSE 5999
5009 IF J > 0 THEN 5010 ELSE 5014
5010 IF A$ = "0" OR A$ = "1" OR A$ = "2" OR A$ = "3" OR A$ = "4" OR A$ = "5" OR A$ = "6" OR A$ = "7" OR A$ = "8" OR A$ = "9" OR A$ = "." THEN 5100 ELSE 5999
5014 COLOR 16, 3
   IF A$ = "T" OR A$ = "t" THEN J = 1: LOCATE 15, 36: PRINT ",K": PRINT
   IF A$ = "L" OR A$ = "l" THEN J = 5: LOCATE 16, 36: PRINT ",opn": PRINT
COLOR 16, 5
   IF A$ = "P" OR A$ = "p" THEN J = 2: LOCATE 15, 54: PRINT ",psia": PRINT
   IF A$ = "R" OR A$ = "r" THEN J = 4: LOCATE 16, 54: PRINT ",mila": PRINT
   IF A$ = "G" OR A$ = "g" THEN J = 6: LOCATE 17, 54: PRINT ",rpm": PRINT
   IF A$ = "C" OR A$ = "c" THEN J = 8: LOCATE 18, 54: PRINT ",in": PRINT
COLOR 16, 6
   IF A$ = "M" OR A$ = "m" THEN J = 3: LOCATE 15, 71: PRINT ",Mach": PRINT
   IF A$ = "N" OR A$ = "n" THEN J = 7: LOCATE 16, 71: PRINT ",rpm": PRINT
COLOR 16, 2
   IF A$ = "B" OR A$ = "b" THEN J = 9: LOCATE 15, 19: PRINT ",psi": PRINT
   IF J = 1 THEN LU = 15: MU = 30
   IF J = 2 THEN LU = 15: MU = 48
   IF J = 3 THEN LU = 15: MU = 65
   IF J = 4 THEN LU = 16: MU = 48
   IF J = 5 THEN LU = 16: MU = 30
   IF J = 6 THEN LU = 17: MU = 48
   IF J = 7 THEN LU = 16: MU = 65
   IF J = 8 THEN LU = 18: MU = 48
   IF J = 9 THEN LU = 15: MU = 13
   IF J > 0 THEN BEEP
GOTO 5999

24
IF J = 1 THEN 5105
IF J = 2 THEN 5405
IF J = 3 THEN 5205
IF J = 4 THEN 5405
IF J = 5 THEN 5405
IF J = 6 THEN 5405
IF J = 7 THEN 5350
IF J = 8 THEN 5405
IF J = 9 THEN 5105

' Assemble Temperature and Liquid Back Pressure Inputs.
5105 XX = XX + 1
D1 = 1; D2 = 2; D3 = 3; D4 = 4; D5 = 5
GOSUB 5500
AA = H1 * 100 + H2 * 10 + H3 + H5 / 10
GOTO 5999

' Assemble Mach Number Input.
5205 XX = XX + 1
D1 = 1; D2 = 3; D3 = 4; D4 = 2; D5 = 5
GOSUB 5500
AA = H2 / 10 + H3 / 100 + H5 / 1000
GOTO 5999

' Assemble Fan Speed Input.
5350 XX = XX + 1
D1 = 1; D2 = 2; D3 = 3; D4 = 5; D5 = 4
GOSUB 5500
AA = H1 * 1000 + H2 * 100 + H3 * 10 + H5
GOTO 5999

' Assemble Pressure, Reynolds Number, Injection Valve, Exhaust Valve, and Chord Inputs.
5405 XX = XX + 1
D1 = 1; D2 = 2; D3 = 4; D4 = 3; D5 = 5
GOSUB 5500
AA = H1 * 10 + H2 + H3 / 10 + H5 / 100
GOTO 5999

5500 IF J = 1 THEN COLOR 0, 3
IF J = 2 THEN COLOR 0, 5
IF J = 3 THEN COLOR 0, 6
IF J = 4 THEN COLOR 0, 5
IF J = 5 THEN COLOR 0, 3
IF J = 6 THEN COLOR 0, 5
IF J = 7 THEN COLOR 0, 6
IF J = 8 THEN COLOR 0, 5
IF J = 9 THEN COLOR 0, 2
IF XX = D1 THEN H1 = VAL(A$): LOCATE LU, MU + D1: PRINT USING "#"; H1
IF XX = D2 THEN H2 = VAL(A$): LOCATE LU, MU + D2: PRINT USING "#"; H2
IF XX = D3 THEN H3 = VAL(A$): LOCATE LU, MU + D3: PRINT USING "#"; H3
IF XX = D4 THEN LOCATE LU, MU + D4: PRINT CHRS(46);
IF XX = D5 THEN H5 = VAL(A$): LOCATE LU, MU + D5: PRINT USING "#"; H5
RETURN

25
*Set Temperature Input.

5600 IF J = 1 THEN 5620 ELSE 5660

5620 STI = AA
   IF STI > MAXT THEN STI = MAXT
   IF STI < MINT THEN STI = MINT
   IF STI < SAT1 THEN STI = SAT1
   COLOR 14, 3
   LOCATE 3, 5: PRINT " AUTO ": PRINT;
   AUTOT = 1
   LOCATE 5, 26: PRINT USING "###.##": STI

*Set Pressure Input.

5660 IF J = 2 THEN 5670 ELSE 5730

5670 SP = AA
   IF SP < MINP THEN SP = MINP
   IF SP > MAXP THEN SP = MAXP
   COLOR 14, 5
   LOCATE 3, 46: PRINT " AUTO ": PRINT;
   LOCATE 6, 43: PRINT " ": PRINT;
   LOCATE 5, 43: PRINT USING "##.##": SP
   AUTOP = 1
   AUTORE = 0

*Set Much Number Input.

5730 IF J = 3 THEN 5740 ELSE 5750

5740 SM = AA
   IF SM < MINM THEN SM = MINM
   IF SM > MAXM THEN SM = MAXM
   COLOR 14, 6
   LOCATE 3, 64: PRINT " AUTO ": PRINT;
   LOCATE 6, 62: PRINT " ": PRINT;
   LOCATE 5, 62: PRINT USING "#.##": SM

*Set Reynolds Number Input.

5750 IF J = 4 THEN 5760 ELSE 5770

5760 SRE = AA
   IF SRE > MAXRE THEN SRE = MAXRE
   IF SRE < MINRE THEN SRE = MINRE
   COLOR 14, 5
   AUTORE = 1
   AUTOP = 1
   LOCATE 6, 43: PRINT USING "###.##": SRE
   LOCATE 3, 46: PRINT " AUTORE ": PRINT;

*Set Liquid Injection Valve Input.

5770 IF J = 5 THEN 5780 ELSE 5810

5780 LCMDS = AA
   COLOR 14, 3
   LOCATE 3, 29: PRINT " MANUAL ": PRINT;
   LOCATE 5, 26: PRINT " ": PRINT;
   LOCATE 6, 26: PRINT " ": PRINT;
   AUTOT = 0

*Set Gas Exhaust Valve Input.

5810 IF J = 6 THEN 5820 ELSE 5860

5820 GCMD = AA
COLOR 14, 5
LOCATE 3, 46: PRINT " MANUAL "; PRINT ;
AUTOP = 0
AUTORE = 0
LOCATE 5, 43: PRINT " "; PRINT ;
LOCATE 6, 43: PRINT " "; PRINT ;

'Set Fan Speed Input.
5860 IF J = 7 THEN 5870 ELSE 5935
5870 NCMDS = AA
IF NCMDS > MAXN THEN NCMDS = MAXN
COLOR 14, 6
LOCATE 5, 62: PRINT " ";
LOCATE 3, 64: PRINT " MANUAL "; PRINT ;
LOCATE 6, 62: PRINT USING "####."; NCMDS
AUTOM = 0

'Set Chord Length Input.
5935 IF J = 8 THEN 5937 ELSE 5943
5937 CHIN = AA
IF CHIN < MINCHIN THEN CHIN = MINCHIN
IF CHIN > MAXCHIN THEN CHIN = MAXCHIN
COLOR 14, 5
LOCATE 20, 48: PRINT USING "##.##"; CHIN
CH = CHIN * .0254

'Set Liquid Back Pressure Input.
5943 IF J = 9 THEN 5944 ELSE 5950
5944 SLQSC = AA
IF SLQSC > MAXLQSC THEN SLQSC = MAXLQSC
COLOR 14, 2
LOCATE 5, 13: PRINT USING "####."; SLQSC
5950 IF J = 0 THEN 5962
IF J = 1 THEN COLOR 14, 3
IF J = 2 THEN COLOR 14, 5
IF J = 3 THEN COLOR 14, 6
IF J = 4 THEN COLOR 14, 5
IF J = 5 THEN COLOR 14, 3
IF J = 6 THEN COLOR 14, 5
IF J = 7 THEN COLOR 14, 6
IF J = 8 THEN COLOR 14, 5
IF J = 9 THEN COLOR 14, 2
LOCATE IU, MU + 1: PRINT "; PRINT ;

5962 IF J > 0 THEN BEEP
IF IE = 1 THEN COLOR 0, 6
IF IE = 1 THEN BEEP; LOCATE 20, 60: PRINT " "; PRINT ;
IF PIE = 1 THEN LOCATE 21, 60: PRINT " "; PIE = 0
IF NIE = 1 THEN LOCATE 21, 60: PRINT " "; NIE = 0
J = 0
XX = 0
IE = 0

5999 RETURN
'Emergency Stop Subroutine.
6000  IE = 1
    COLOR 20, 8
    LOCATE 20, 60: PRINT " EMERGENCY STOP ": PRINT ;
    COLOR 4, 8
    IF PIE = 1 THEN LOCATE 21, 60: PRINT " Pressure Limit ";
    IF PIE = 1 THEN LOCATE 21, 60: PRINT " Fan RPM Limit ";
    COLOR 4, 8
    AUTOT = 0
    AUTOP = 0
    AUTOM = 0
    AUTORE = 0
    LOCATE 3, 29: PRINT " MANUAL ": PRINT ;
    LOCATE 3, 46: PRINT " MANUAL ": PRINT ;
    LOCATE 3, 64: PRINT " MANUAL ": PRINT ;
    RETURN

'Analog to Digital Conversion Input Subroutine.
8000  OUT COMMAND.REGISTER, ZSTOP
    ZEMP = INP(ZATA.REGISTER)
    WAIT ZSTATUS.REGISTER, ZOMMAND.WAIT
    OUT ZOMMAND.REGISTER, ZCLEAR
    ZDGAIN = 1
    FOR I = 1 TO 7
        ZDCINL = I - 1
        WAIT ZSTATUS.REGISTER, WRITE.WAIT, WRITE.WAIT
        WAIT ZSTATUS.REGISTER, ZOMMAND.WAIT
        OUT ZOMMAND.REGISTER, ZADIN
        WAIT ZSTATUS.REGISTER, WRITE.WAIT, WRITE.WAIT
        OUT ZATA.REGISTER, ZDGAIN
        WAIT ZSTATUS.REGISTER, WRITE.WAIT, WRITE.WAIT
        OUT ZATA.REGISTER, ZDCINL
        WAIT ZSTATUS.REGISTER, READ.WAIT
        ZOW = INP(ZATA.REGISTER)
        WAIT ZSTATUS.REGISTER, READ.WAIT
        ZIGII = INP(ZATA.REGISTER)
        ZOLT# = ZIGII * 256 + ZOW
            IF ZOLT# > 32767 THEN ZOLT# = ZOLT# - 65536!
            WAIT ZSTATUS.REGISTER, ZOMMAND.WAIT
            ZSTATUS = INP(ZSTATUS.REGISTER)
            IF (ZSTATUS AND &1180) THEN GOTO 8000
            ZOL.# = 5 * ZOLT# / 32768
            E(I) = ZOL.#
        NEXT I

'Sensor Failure Detection.
E11 = E(1): IF E11 < 0 THEN E11 = 0
    IF E(1) < .43 THEN E(1) = .43: FL.10 = 1
E12 = E(2): IF E12 < 0 THEN E12 = 0
    IF E(2) < .4 THEN E(2) = .4: FL.10 = 2
    IF E(3) < 0 THEN E(3) = 0: FL.10 = 3
    IF E(4) < 0 THEN E(4) = 0: FL.10 = 4
    IF E(5) < .001 THEN E(5) = .001
    IF E(6) < .3 THEN E(6) = .3
    IF ABS(E(7)) > 1 THEN FL.10 = 7
    IF FL.10 >= 1 THEN 8340 ELSE 8380
8340  COLOR 4, 8
LOCATE 21, 60: PRINT " Sensor Failure "; PRINT;
    IF FL10 = 1 THEN LOCATE 22, 60: PRINT " Total Pressure ";
    IF FL10 = 2 THEN LOCATE 22, 60: PRINT " Static Pressure ";
    IF FL10 = 3 THEN LOCATE 22, 60: PRINT " Gas Temperature ";
    IF FL10 = 4 THEN LOCATE 22, 60: PRINT " Wall Temperature";
    IF FL10 = 7 THEN LOCATE 22, 60: PRINT " Screen Pressure ";
GOSUB 6000
GOTO 8400
8380 COLOR 6, 6
LOCATE 21, 60: PRINT "; PRINT;
LOCATE 22, 60: PRINT "; PRINT;
8400 FL10 = 0
RETURN

*Digital to Analog Conversion Output Subroutine.
9000 FOR IK = 1 TO 7
    DR1 = INT(DAC(IK) * 4095)
    HI = INT(DR1 / 16)
    DR2 = INT(DR1 - HI * 16)
    IF IK < 3 THEN 9050 ELSE 9070
9050 LO = INT(DR2 * 16) + 2 * IK - 2
GOTO 9080
9070 LO = INT(DR2 * 16) + 2 * IK - 1
9080 BEMP = INP(&II225)
    IF BEMP = 0 THEN 9110
9100 GOTO 9080
9110 OUT &II224, LO
9120 CEMP = INP(&II225)
    IF CEMP = 16 THEN 9150
GOTO 9120
9150 OUT &II224, HI
NEXT IK
RETURN
10000 END
Appendix B
Controller Simulator Source Code Listing

0.3-m Transonic Cryogenic Tunnel Controller Simulator.
CLS
CLEAR

Program Constants.
DEL = .1
CGV = 8
CII = .18
CIIIN = .18 * .0245
CLQV = 4
IW = 39
K = 1
KDI = 0!
KDP = 0!
KDT = 0!
KIL = .02
KIM = 0!
KIN = .4
KIP = .05
KIP' = .1
KMM = .3
KP = .3
KPL = .2
KPM = 4.5
KPN = .6
KPP = 1!
KPT = 1!
KT = .04
MXT = 40
PL01 = 3!
PLQ = 3!
PP = 1!
PPI = 1!
SLQSC = 17!
STP = 300!
TMWL = 300!
TMWL1 = 300!
TT = 300!
TT1 = 300!

'Maximum - Minimum Limits Screen Layout.
COLOR 14, 9
CLS
LOCATE 3, 16: PRINT " Maximum - Minimum Limits for 0.3-m TCT Controller ",
COLOR 12, 9
LOCATE 5, 25: PRINT "Tunnel"
LOCATE 6, 24: PRINT "Maximum"
LOCATE 5, 38: PRINT "Set"
LOCATE 6, 36: PRINT "Maximum"
LOCATE 5, 60: PRINT "Set"
LOCATE 6, 58: PRINT "Minimum"
LOCATE 5, 72: PRINT "Tunnel"
LOCATE 6, 71: PRINT "Minimum"

COLOR 7, 9
LOCATE 7, 3: PRINT "Temperature"
LOCATE 8, 4: PRINT "(kelvin)"
LOCATE 10, 3: PRINT "Pressure"
LOCATE 11, 4: PRINT "(psia)"
LOCATE 13, 3: PRINT "Normal Fan Speed"
LOCATE 14, 4: PRINT "(rpm)"
LOCATE 16, 3: PRINT "Mach Number"
LOCATE 19, 3: PRINT "Reynolds Number"
LOCATE 20, 4: PRINT "(Mln)"
LOCATE 22, 3: PRINT "Accept Tunnel Max./Min. Limits and Start 0.3-m TCT Controller." LOCATE 23, 3: PRINT "Accept Set Max./Min. Limits and Start 0.3-m TCT Controller."

COLOR 15, 9
LOCATE 7, 51: PRINT "T"
LOCATE 7, 49: PRINT CHR$(243)
LOCATE 7, 53: PRINT CHR$(243)
LOCATE 10, 51: PRINT "P"
LOCATE 10, 49: PRINT CHR$(243)
LOCATE 10, 53: PRINT CHR$(243)
LOCATE 13, 51: PRINT "N"
LOCATE 13, 49: PRINT CHR$(243)
LOCATE 13, 53: PRINT CHR$(243)
LOCATE 16, 51: PRINT "M"
LOCATE 16, 49: PRINT CHR$(243)
LOCATE 16, 53: PRINT CHR$(243)
LOCATE 19, 51: PRINT "R"
LOCATE 19, 49: PRINT CHR$(243)
LOCATE 19, 53: PRINT CHR$(243)

COLOR 14, 9
LOCATE 7, 3: PRINT "T"
LOCATE 10, 3: PRINT "P"
LOCATE 13, 3: PRINT "N"
LOCATE 16, 3: PRINT "M"
LOCATE 19, 3: PRINT "R"
LOCATE 22, 3: PRINT "A"
LOCATE 23, 10: PRINT "S"

"Tunnel Maximum - Minimum Limits.
MAXT1 = 340!
MINT1 = 77!
MAXP1 = 88!
MINP1 = 14.696
MAXN1 = 5600!
MINN1 = 0!
MAXM1 = .995
MINM1 = .15
MAXREI = 50!
MINREI = 1!
MAXCHIN = 15.75
MINCHIN = .394
MAXCHI = .4
MINCHI = .01
MAXI.QSC = 150!
MAXSPR = MAXP1 / 14.696
MINSPR = MINP1 / 14.696

MAXT = MAXT1
MINT = MINT1
MAXP = MAXP1
MINP = MINP1
MAXN = MAXN1
MINN = MINN1
MAXM = MAXM1
MINM = MINM1
MAXRE = MAXRE1
MINRE = MINRE1

COLOR 10, 9
LOCATE 7, 25: PRINT USING "###.#"; MAXT1
LOCATE 7, 37: PRINT USING "###.#"; MAXT1
LOCATE 10, 25: PRINT USING "###.#"; MAXP1
LOCATE 10, 59: PRINT USING "##.##"; MINP1
LOCATE 13, 25: PRINT USING "###.#"; MAXN1
LOCATE 13, 60: PRINT USING "####."; MINN1
LOCATE 16, 25: PRINT USING "###.#"; MAXM1
LOCATE 16, 60: PRINT USING "####."; MINM1
LOCATE 19, 25: PRINT USING "###.#"; MAXRE1
LOCATE 19, 60: PRINT USING "####."; MINRE1
LOCATE 7, 69: PRINT "Saturation"
LOCATE 8, 69: PRINT "Temperature"
LOCATE 10, 71: PRINT "Ambient"
LOCATE 11, 71: PRINT "Pressure"
LOCATE 13, 73: PRINT USING "####."; MINN1
LOCATE 16, 73: PRINT USING "####."; MINM1
LOCATE 19, 73: PRINT USING "####."; MINRE1

'Maximum - Minimum Limits Inputs.
5 A$ = INKEY$
   IF A$ = "T" OR A$ = "t" THEN GOSUB 10
   IF A$ = "P" OR A$ = "p" THEN GOSUB 100
   IF A$ = "N" OR A$ = "n" THEN GOSUB 200
   IF A$ = "M" OR A$ = "m" THEN GOSUB 300
   IF A$ = "R" OR A$ = "r" THEN GOSUB 400
   IF A$ = "A" OR A$ = "a" THEN 500
   IF A$ = "S" OR A$ = "s" THEN 600
GOTO 5

'Temperature Minimum Limit Subroutine.
10 COLOR 15, 9
   BEEP
   LR = 7
   LC = 58
   LOCATE LR, LC + 1: PRINT ",K"
   XX = 0
20 BS$ = INKEY$
   IF BS$ = "D" OR BS$ = "d" THEN 30 ELSE 40
30 LOCATE LR, LC + 1: PRINT " "
   RETURN
40 IF BS$ = "0" OR BS$ = "1" OR BS$ = "2" OR BS$ = "3" OR BS$ = "4" OR BS$ = "5" OR BS$ =
"6" OR B$ = "7" OR B$ = "8" OR B$ = "9" OR B$ = "." THEN 50 ELSE 20

50

XX = XX + 1
IF XX = 1 THEN H1 = VAL(B$): LOCATE LR, LC + 1: PRINT USING ";#"; H1
IF XX = 2 THEN H2 = VAL(B$): LOCATE LR, LC + 2: PRINT USING ";#"; H2
IF XX = 3 THEN H3 = VAL(B$): LOCATE LR, LC + 3: PRINT USING ";#"; H3
IF XX = 4 THEN LOCATE LR, LC + 4: PRINT CHR$(46)
IF XX = 5 THEN H5 = VAL(B$): LOCATE LR, LC + 5: PRINT USING ";#"; H5
IF XX = 5 THEN 60 ELSE 20

60

AA = H1 * 100 + H2 * 10 + H3 + H5 / 10
MINT = AA
IF MINT >= MAXT THEN MINT = MAXT
IF MINT <= MINT THEN MINT = MINT

70

CS = INKEY$
IF CS = CHR$(13) THEN 80 ELSE 70
BEEP
COLOR 14, 9
LOCATE LR, LC + 1: PRINT USING "####, "; MINT
RETURN

'Pressure Maximum Limit Subroutine.
100

COLOR 15, 9
BEEP
COLOR 14, 9
LOCATE LR, LC + 1: PRINT " " ,psia
XX = 0

110

B$ = INKEY$
IF B$ = "D" OR B$ = "d" THEN 120 ELSE 130
LOCATE LR, LC + 1: PRINT ";"
RETURN

120

IF B$ = "0" OR B$ = "1" OR B$ = "2" OR B$ = "3" OR B$ = "4" OR B$ = "5" OR B$ = "6" OR B$ = "7" OR B$ = "8" OR B$ = "9" OR B$ = "." THEN 140 ELSE 110

130

XX = XX + 1
IF XX = 1 THEN H1 = VAL(B$): LOCATE LR, LC + 1: PRINT USING "##, "; H1
IF XX = 2 THEN H2 = VAL(B$): LOCATE LR, LC + 2: PRINT USING "##, "; H2
IF XX = 4 THEN H3 = VAL(B$): LOCATE LR, LC + 4: PRINT USING "##, "; H3
IF XX = 3 THEN LOCATE LR, LC + 3: PRINT CHR$(46)
IF XX = 5 THEN H5 = VAL(B$): LOCATE LR, LC + 5: PRINT USING "##, "; H5
IF XX = 5 THEN 150 ELSE 110

150

AA = H1 * 10 + H2 * 10 + H3 / 10 + H5 / 100
MAXP = AA
IF MAXP <= MINP THEN 160 ELSE 170

160

MAXP = MINP
COLOR 20, 8: LOCATE LR + 1, 36: PRINT " Warning! Set Max. = Tunnel Min. "
FL0 = 1
GOTO 180

170

COLOR 14, 9: LOCATE LR + 1, 36: PRINT " 
FL0 = 0
IF MAXP > MAXP THEN MAXP = MAXP

180

CS = INKEY$
IF CS = CHR$(13) THEN 195 ELSE 190
BEEP
COLOR 14, 9
LOCATE LR, LC + 1: PRINT USING "####, "; MAXP
RETURN

33
'Normal Fan Speed Maximum Limit Subroutine.
200 COLO R 15, 9
201 BEEP
202 LC = 36
203 LR = 13
204 LOCATE LR, LC + 1: PRINT "rpm"
205 XX = 0
210 BS = INKEY$
211 IF BS = "D" OR BS = "d" THEN 220 ELSE 230
220 LOCATE LR, LC + 1: PRINT ""
221 RETURN
230 IF BS = "0" OR BS = "1" OR BS = "2" OR BS = "3" OR BS = "4" OR BS = "5" OR BS = "6" OR BS = "7" OR BS = "8" OR BS = "9" OR BS = "." THEN 240 ELSE 210
240 XX = XX + 1
241 IF XX = 1 THEN H1 = VAL(B$): LOCATE LR, LC + 1: PRINT USING ","; H1
242 IF XX = 2 THEN H2 = VAL(B$): LOCATE LR, LC + 2: PRINT USING ","; H2
243 IF XX = 3 THEN H3 = VAL(B$): LOCATE LR, LC + 3: PRINT USING ","; H3
244 IF XX = 4 THEN H5 = VAL(B$): LOCATE LR, LC + 4: PRINT USING ","; H5
245 IF XX = 5 THEN 250 ELSE 210
250 AA = H1 * 1000 + H2 * 100 + H3 * 10 + H5
251 MAXN = AA
252 IF MAXN <= MINN1 THEN 260 ELSE 270
260 MAXN = MINN1
261 COLOR 20, 8: LOCATE LR + 1, 36: PRINT " Warning! Set Max. = Tunnel Min."
262 FLO = 1
263 GOTO 280
267 COLOR 14, 9: LOCATE LR + 1, 36: PRINT ""
268 FLO = 0
270 IF MAXN > MAXN1 THEN MAXN = MAXN1
270 CS = INKEY$
271 IF CS = CHR$(13) THEN 295 ELSE 290
275 BEEP
276 COLOR 14, 9
277 LOCATE LR, LC + 1: PRINT USING "####.", MAXN
278 RETURN

'Mach Number Maximum Limit Subroutine.
300 COLOR 15, 9
301 BEEP
302 LC = 36
303 LR = 16
304 LOCATE LR, LC + 1: PRINT "Mach"
305 XX = 0
310 BS = INKEY$
311 IF BS = "D" OR BS = "d" THEN 320 ELSE 330
320 LOCATE LR, LC + 1: PRINT ""
321 RETURN
330 IF BS = "0" OR BS = "1" OR BS = "2" OR BS = "3" OR BS = "4" OR BS = "5" OR BS = "6" OR BS = "7" OR BS = "8" OR BS = "9" OR BS = "." THEN 340 ELSE 310
340 XX = XX + 1
341 IF XX = 1 THEN H1 = VAL(B$): LOCATE LR, LC + 1: PRINT USING ","; H1
342 IF XX = 3 THEN H2 = VAL(B$): LOCATE LR, LC + 3: PRINT USING ","; H2
343 IF XX = 4 THEN H3 = VAL(B$): LOCATE LR, LC + 4: PRINT USING ","; H3
344 IF XX = 2 THEN LOCATE LR, LC + 2: PRINT CHR$(46)
345 IF XX = 5 THEN H5 = VAL(B$): LOCATE LR, LC + 5: PRINT USING ","; H5
346 IF XX = 5 THEN 350 ELSE 310

34
'Reynolds Number Maximum Limit Subroutine.

400  COLOR 15, 9
    BEEP
    LC = 36
    LR = 19
    LOCATE LR, LC + 1: PRINT "Min"  
    XX = 0
410  BS = INKEY
    IF BS = "D" OR BS = "d" THEN 420 ELSE 430
420  LOCATE LR, LC + 1: PRINT "  "
    RETURN
430  IF BS = "0" OR BS = "1" OR BS = "2" OR BS = "3" OR BS = "4" OR BS = "5" OR BS = "6" OR BS = "7" OR BS = "8" OR BS = "9" OR BS = ":. " THEN 440 ELSE 410
440  XX = XX + 1
    IF XX = 1 THEN II1 = VAL(B$): LOCATE LR, LC + 1: PRINT USING ":#", II1
    IF XX = 2 THEN II2 = VAL(B$): LOCATE LR, LC + 2: PRINT USING ":#, II2
    IF XX = 4 THEN II3 = VAL(B$): LOCATE LR, LC + 4: PRINT USING ":#, II3
    IF XX = 3 THEN LOCATE LR, LC + 3: PRINT CHR$(46)
    IF XX = 5 THEN II5 = VAL(B$): LOCATE LR, LC + 5: PRINT USING ":#, II5
    IF XX = 5 THEN 450 ELSE 410
450  AA = 111 * 10 + II2 + II3 / 10 + II5 / 100
    MAXRE = AA
    IF MAXRE <= MINRE1 THEN 460 ELSE 470
460  MAXRE = MINRE1
    COLOR 20, 8: LOCATE LR + 1, 36: PRINT " Warning! Set Max. = Tunnel Min. "
    FL0 = 1
    GOTO 480
470  COLOR 14, 9: LOCATE LR + 1, 36: PRINT "  "
    FL0 = 0
480  CS = INKEY
    IF CS = CHR$(13) THEN 495 ELSE 490
490  BEEP
    COLOR 14, 9
    LOCATE LR, LC + 1: PRINT USING "###", MAXRE
    RETURN

'Starts the Controller with the Tunnel Maximum - Minimum Limits.

500  XX = 0
    GOTO 800
Starts the Controller with the Set Maximum - Minimum Limits.

600 IF X1.0 = 1 THEN GOTO 5

XX = 0
MAXSPR = MAXP / 14.696
MINSPR = MINP / 14.696
GOTO 800

'Controller Simulation.
'Controller Screen Layout.

800 COLOR 0, 0

COLOR 15, 4
LOCATE 1, 26: PRINT " 0.3-m TUNNEL T-P/R-M CONTROLLER "

FOR I = 2 TO 25
COLOR 15, 1
LOCATE I, 2: PRINT STRINGS(10, 0);
IF I = 4 THEN LOCATE 4, 2: PRINT STRINGS(10, 205);
IF I = 14 THEN LOCATE 14, 2: PRINT STRINGS(10, 205);
IF I = 19 THEN LOCATE 19, 2: PRINT STRINGS(10, 205);
IF I = 23 THEN LOCATE 23, 2: PRINT STRINGS(18, 205);
COLOR 15, 2
LOCATE I, 12: PRINT STRINGS(12, 0);
IF I = 4 THEN LOCATE 4, 12: PRINT STRINGS(12, 205);
IF I = 14 THEN LOCATE 14, 12: PRINT STRINGS(12, 205);
IF I = 19 THEN LOCATE 19, 12: PRINT STRINGS(12, 205);
IF I = 23 THEN LOCATE 23, 12: PRINT STRINGS(18, 205);
COLOR 15, 3
LOCATE I, 24: PRINT STRINGS(17, 0);
IF I = 4 THEN LOCATE 4, 24: PRINT STRINGS(17, 205);
IF I = 14 THEN LOCATE 14, 24: PRINT STRINGS(17, 205);
IF I = 19 THEN LOCATE 19, 24: PRINT STRINGS(17, 205);
IF I = 23 THEN LOCATE 23, 24: PRINT STRINGS(18, 205);
COLOR 15, 5
LOCATE I, 41: PRINT STRINGS(18, 0);
IF I = 4 THEN LOCATE 4, 41: PRINT STRINGS(18, 205);
IF I = 14 THEN LOCATE 14, 41: PRINT STRINGS(18, 205);
IF I = 19 THEN LOCATE 19, 41: PRINT STRINGS(18, 205);
IF I = 23 THEN LOCATE 23, 41: PRINT STRINGS(18, 205);
COLOR 15, 6
LOCATE I, 59: PRINT STRINGS(18, 0);
IF I = 4 THEN LOCATE 4, 59: PRINT STRINGS(18, 205);
IF I = 14 THEN LOCATE 14, 59: PRINT STRINGS(18, 205);
IF I = 19 THEN LOCATE 19, 59: PRINT STRINGS(18, 205);
IF I = 23 THEN LOCATE 23, 59: PRINT STRINGS(18, 205);
NEXT I

COLOR 15, 2
LOCATE 2, 14: PRINT " LN PUMP ": PRINT ;
LOCATE 3, 14: PRINT " AUTO ": PRINT ;
LOCATE 5, 18: PRINT ",psia": PRINT ;
LOCATE 9, 18: PRINT ",psia": PRINT ;
LOCATE 12, 18: PRINT ",%opn": PRINT ;
LOCATE 15, 12: PRINT " =": PRINT ;
LOCATE 5, 13: PRINT USING "###.#": SI,OSC .

36
COLOR 14, 2
LOCATE 15, 12: PRINT "IP": PRINT ;

COLOR 15, 3
LOCATE 2, 28: PRINT "TEMP LOOP": PRINT ;
LOCATE 3, 29: PRINT " MANUAL ": PRINT ;
LOCATE 5, 31: PRINT "K(Final)": PRINT ;
LOCATE 6, 31: PRINT "K(Used)": PRINT ;
LOCATE 9, 31: PRINT "K-GN2": PRINT ;
LOCATE 10, 31: PRINT "K-WALL": PRINT ;
LOCATE 12, 31: PRINT "%open": PRINT ;
LOCATE 15, 25: PRINT " cmplevel": PRINT ;
LOCATE 16, 25: PRINT "A Q%": PRINT ;
LOCATE 20, 25: PRINT "GRAD= K/mt": PRINT ;
LOCATE 21, 25: PRINT " SAT= K": PRINT ;
LOCATE 24, 32: PRINT "I";
LOCATE 24, 30: PRINT CHR$(243);
LOCATE 24, 34: PRINT CHR$(243);
LOCATE 24, 36: PRINT USING "###": MINT;
LOCATE 24, 36: PRINT USING "###": MAXT;

COLOR 14, 3
LOCATE 15, 25: PRINT "I": PRINT ;
LOCATE 16, 26: PRINT "I": PRINT ;

COLOR 15, 5
LOCATE 2, 45: PRINT "P fRe LOOP": PRINT ;
LOCATE 3, 46: PRINT " MANUAL ": PRINT ;
LOCATE 5, 48: PRINT "pia": PRINT ;
LOCATE 6, 48: PRINT "Miln": PRINT ;
LOCATE 20, 42: PRINT "CHORD= 7.09,in": PRINT ;
LOCATE 9, 48: PRINT "pia": PRINT ;
LOCATE 21, 42: PRINT "P st= pia": PRINT ;
LOCATE 22, 42: PRINT "Del P= pia": PRINT ;
LOCATE 10, 48: PRINT "Miln": PRINT ;
LOCATE 12, 48: PRINT "%open V": PRINT ;
LOCATE 13, 48: PRINT "%open V2": PRINT ;
LOCATE 15, 43: PRINT " rcs": PRINT ;
LOCATE 16, 43: PRINT " yno": PRINT ;
LOCATE 17, 43: PRINT "A v%": PRINT ;
LOCATE 18, 43: PRINT " hrd": PRINT ;
LOCATE 24, 50: PRINT "P";
LOCATE 24, 48: PRINT CHR$(243);
LOCATE 24, 52: PRINT CHR$(243);
LOCATE 24, 43: PRINT USING "###": MINP;
LOCATE 24, 43: PRINT USING "###": MAXP;
LOCATE 25, 50: PRINT "R";
LOCATE 25, 48: PRINT CHR$(243);
LOCATE 25, 52: PRINT CHR$(243);
LOCATE 25, 43: PRINT USING "###": MINRE;
LOCATE 25, 43: PRINT USING "###": MAXRE;

COLOR 14, 5
LOCATE 15, 43: PRINT "P": PRINT ;
LOCATE 16, 43: PRINT "R": PRINT ;
LOCATE 17, 44: PRINT "G": PRINT ;
COLOR 15, 6
LOCATE 2, 62: PRINT "RPM/MACH LOOP": PRINT
LOCATE 3, 64: PRINT "MANUAL ": PRINT;
LOCATE 5, 67: PRINT "Mach": PRINT;
LOCATE 6, 67: PRINT "RPM": PRINT;
LOCATE 9, 67: PRINT "Mach": PRINT;
LOCATE 10, 67: PRINT "RPM": PRINT;
LOCATE 12, 67: PRINT "%, RhsT": PRINT;
LOCATE 15, 61: PRINT "mach": PRINT;
LOCATE 16, 61: PRINT "rpm": PRINT;
LOCATE 24, 68: PRINT "N";
LOCATE 24, 66: PRINT CHR$(243);
LOCATE 24, 70: PRINT CHR$(243);
LOCATE 24, 61: PRINT USING "####": MINN;
LOCATE 24, 72: PRINT USING "#####": MAXN;
LOCATE 25, 68: PRINT "M";
LOCATE 25, 66: PRINT CHR$(243);
LOCATE 25, 70: PRINT CHR$(243);
LOCATE 25, 61: PRINT USING "###": MINM;
LOCATE 25, 72: PRINT USING "###": MAXM;

COLOR 14, 6
LOCATE 15, 61: PRINT "M": PRINT;
LOCATE 16, 61: PRINT "N": PRINT;

COLOR 15, 1
LOCATE 5, 3: PRINT "SET POINT": PRINT;
LOCATE 9, 3: PRINT "PROCESS": PRINT;
LOCATE 12, 3: PRINT "COMMAND": PRINT;
LOCATE 15, 3: PRINT "INPUTS": PRINT;
LOCATE 20, 3: PRINT "STATUS": PRINT;
LOCATE 16, 3: PRINT "delete": PRINT;
LOCATE 24, 3: PRINT "LIMITS";

COLOR 14, 1
LOCATE 16, 3: PRINT "D": PRINT;

"Simulation Controller Program.
1000 CRPM = FRPM
   IF CRPM < 0 THEN CRPM = 0
   IF CRPM < 50 THEN CRPM = 50
CRM = 2.77 * CRPM / 157 / SQR(TT) * PP ^ .035
   IF CRM < .001 THEN CRM = .001
M = 1.67 - SQR(CRM)
   IF M > .999 THEN M = .999
PS = PP / (1 + .2 * M ^ 2) ^ 3.5
PPUSCS = PP * 14.696
PSUSCS = PS * 14.696
PLUSCS = PLQ * 14.696

GOSUB 5000

MF = (1 + .2 * M * M)
KRE = 63714 * CHI * M / TT ^ 1.4 / (MF) ^ 2.1
RE = KRE * PP
\[
\begin{align*}
\text{SAT} &= 50 + 27.34 \times \text{PS}^{.296} \\
\text{SAT}_1 &= \text{SAT} \times \text{MF} \\
\text{LDPQ} &= (\text{PLQ} - \text{PP}) \\
\text{IF} \ LDPQ < .5 \ \text{THEN} \ LDPQ = .5 \\
\text{LF} &= \text{CLQV} \times .8676 \times \text{SQR}(\text{LDPQ}) \\
\text{DRPM} &= \text{FRPM} \\
\text{IF} \ DRPM < 100 \ \text{THEN} \ DRPM = 100 \\
\text{KTGS} &= \text{DRPM} \times \text{SQR}(\text{PP}) \times \text{KT} / 3! / \text{TT} / \text{LF} \\
\text{TTMP} &= \text{TT} \\
\text{IF} \ TTMP < 80 \ \text{THEN} \ TTMP = 80 \\
\text{FKW} &= 100 \times \text{PP} \times (\text{FRPM} / 1000)^2.26 / \text{SQR}(\text{TTMP}) \\
\text{FB} &= \text{FKW} / (121 + \text{TT}) / \text{LF} \\
\text{SPR} &= \text{SP} / 14.696 \\
\text{SPR1} &= \text{SPR} / \text{KRE} \\
\text{IF} \ \text{SPR1} > \text{MAXSPR} \ \text{THEN} \ \text{SPR1} = \text{MAXSPR} \\
\text{IF} \ \text{SPR1} < \text{MINSPR} \ \text{THEN} \ \text{SPR1} = \text{MINSPR} \\
\text{IF} \ \text{AUTORE} = 1 \ \text{THEN} \ \text{SPR} = \text{SPR1} \\
\text{SPRU} &= \text{SPR} \times 14.696 \\
\text{COLOR} &= 14, 5 \\
\text{IF} \ \text{AUTORE} = 1 \ \text{THEN} \ \text{LOCATE} 5, 43 : \text{PRINT USING} \ "##.##" ; \text{SPRU}
\end{align*}
\]

'Temperature Control Loop.

\[
\begin{align*}
\text{IF} \ \text{IE} = 1 \ \text{THEN} \ 2950 \\
\text{IF} \ (\text{TMWL} - \text{TT}) > 1.5 \ \times \text{MXT} \ \text{THEN} \ 2950 \\
\text{IF} \ \text{FRPM} < 580 \ \text{THEN} \ 2950 \\
\text{ST} &= \text{ST1} \\
\text{IF} \ \text{ST} > \text{TT} \ \text{THEN} \ 2530 \ \text{ELSE} \ 2525 \\
2525 & \text{IF} \ \text{ST} < (\text{STP} - .04) \ \text{THEN} \ \text{ST} = (\text{STP} - .04) \\
2530 & \text{IF} \ \text{AUTOT} = 1 \ \text{THEN} \ 2540 \ \text{ELSE} \ 2565 \\
2540 & \text{IF} \ \text{AUTOP} = 0 \ \text{THEN} \ 2610 \\
2560 & \text{IF} \ \text{ABS}(\text{PP} - \text{SPR}) < .15 \ \text{THEN} \ 2560 \ \text{ELSE} \ 2570 \\
2570 & \text{IF} \ (\text{PP} / \text{TT}) > .95 \times (\text{SPR} / \text{ST}) \ \text{THEN} \ 2610 \ \text{ELSE} \ 2580 \\
2580 & \text{IF} \ \text{TT} > \text{ST} \ \text{THEN} \ 2610 \ \text{ELSE} \ 2590 \\
2590 & \text{ST} = \text{TT} - .02 \\
2610 & \text{IF} \ (\text{TMWL} - \text{ST} - \text{MXT}) > 0 \ \text{THEN} \ 2620 \ \text{ELSE} \ 2650 \\
2620 & \text{ST} = \text{TMWL} - \text{MXT} \\
\text{FB} &= 0 \\
2650 & \text{IF} \ \text{ST} < \text{SAT1} \ \text{THEN} \ \text{ST} = \text{SAT1} \\
\text{ET} &= \text{TT} - \text{ST} \\
2700 & \text{IF} \ \text{ABS}(\text{TT} - \text{ST1}) < .3 \ \text{THEN} \ \text{FL1} = 1 \ \text{ELSE} \ \text{FL1} = 0 \\
2700 & \text{IF} \ \text{ABS}(\text{TMWL} - \text{TT}) < 24 \ \text{THEN} \ \text{FL2} = 1 \ \text{ELSE} \ \text{FL2} = 0 \\
2700 & \text{IF} \ \text{ET} < -5 \ \text{THEN} \ \text{FF} = 0 \\
2700 & \text{IF} \ \text{ET} > 0 \ \text{THEN} \ \text{IF} = 1 \\
\text{FBB} &= \text{FB} \times \text{FF} \times .8 \\
\text{RIT} &= \text{RITM1} + \text{KIT} \times \text{KTGS} \times \text{DEL} \times \text{ET} \\
2750 & \text{IF} \ \text{RIT} < -\text{FBB} \ \text{THEN} \ \text{RIT} = -\text{FBB} \\
2750 & \text{IF} \ \text{RIT} > (1 - \text{FB}) \ \text{THEN} \ \text{RIT} = (1 - \text{FB}) \\
2750 & \text{IF} \ (\text{TMWL} - \text{TT}) > \text{MXT} / 2 \ \text{THEN} \ 2750 \ \text{ELSE} \ 2780 \\
2780 & \text{LMT} = 1 - (\text{TMWL} - \text{TT} - \text{MXT} / 2) / 2 / \text{MXT} \\
2780 & \text{IF} \ \text{LMT} < 1! / \text{LF} \ \text{THEN} \ \text{LMT} = 1! / \text{LF} \\
2780 & \text{IF} \ \text{RIT} > \text{LMT} \ \text{THEN} \ \text{RIT} = \text{LMT} \\
2820 & \text{IF} \ \text{ALQ} < 0 \ \text{THEN} \ \text{ALQ} = 0 \\
2820 & \text{IF} \ \text{ALQ} > 1 \ \text{THEN} \ \text{ALQ} = 1 \\
2820 & \text{IF} \ (\text{TMWL} - \text{TT}) > \text{MXT} / 2 \ \text{THEN} \ 2820 \ \text{ELSE} \ 2830 \\
2820 & \text{IF} \ \text{ALQ} > \text{LMT} \ \text{THEN} \ \text{ALQ} = \text{LMT}
\end{align*}
\]
2830  L.CMDS = ALQ * 100
GOTO 2970
2850  IF LCMDS > 100 THEN LCMDS = 100
       ALQ = LCMDS / 100
       IF (TMWL - TT) > MXT / 2 THEN 2880 ELSE 2910
2880  I,MT = 1 - ((TMWL - TT - MXT / 2) * 2 / MXT
       IF I,MT < 1! THEN I,MT = 1! / 1!
       IF ALQ > I,MT THEN ALQ = I,MT
2910  RTI = ALQ
GOTO 2970
2950  ALQ = 0
       LCMDS = 0
2970  IF ALQ > ALQP + .01 THEN ALQ = ALQP + .01
       DAC(1) = ALQ
       DAC(2) = ALQ

'Pressure - Reynolds Number Control Loop.
KPGS = 750 * KP / PP / SQRT(TT)
GF1 = 2.725 * CGV * PP / SQRT(TT)
       IF PPUSCS > MAXP1 THEN PIE = 1: GOSUB 6000
       IF IE = 1 THEN 3220
       IF ABS(RE - SRE) < .05 THEN FL = 1 ELSE FL = 0
       IF AUTOP = 1 THEN 3040 ELSE 3180
3040  EP = PP - SPR
       IF ABS(EP) < .005 THEN FL = 1 ELSE FL = 0
       RIP = RIPM1 + EP * KPGS * KIP * DEL.
       IF RIP < 0 THEN RIP = 0
       IF RIP > 1! THEN RIP = 1!
       AGV1 = KPGS * (KPP * EP + KDP * (EP - 2 * EPM1 + EPM2) / 2 / DEL) + RIP
       IF AGV1 < 0 THEN AGV1 = 0
       IF AGV1 > 1! THEN AGV1 = 1!
       IF AGV1 > .9 THEN AGV2 = AGV2 + .01
       IF AGV1 < .7 THEN AGV2 = AGV2 - .01
       IF AGV2 < 0 THEN AGV2 = 0
       IF AGV2 > 1! THEN AGV2 = 1!
       GCMDS = AGV1 * 100
GOTO 3240
3180  IF GCMDS > 100 THEN GCMDS = 100
       RIP = GCMDS / 100
       AGV1 = GCMDS / 100
       IF FRPM > 300 THEN LCMDS = 0
GOTO 3240
3220  AGV1 = 1!
       GCMDS = 100
3240  IF AGV1 < AGV1P - .05 THEN AGV1 = AGV1P - .05
       IF AGV1 > AGV1P + .05 THEN AGV1 = AGV1P + .05
       DAC(4) = AGV1 * .8 + .2
       DAC(5) = AGV2 * .8 + .2

'Fan Speed - Mach Number Control Loop.
IF IE = 1 THEN 3405 ELSE 3410
3405  NCMDSI = 0
GOTO 3550
3410  NCMDSI = NCMDS
       IF FRPM > MAXNI THEN NIE = 1: GOSUB 6000
       IF AUTOM = 1 THEN 3422 ELSE 3550
3422  IF FRPM < 580 THEN AUTOM = 0: GOTO 3435
FKM = 1 - .5 * M
   IF FKM < .71 THEN FKM = .71
KMC = 520 * SQR(TT) * FKM / PP ^ .035
KMGS = KMC * KMM
   IF ALQ > .99 THEN 3432 ELSE 3440

3432 AUTOM = 0
NCMDS = FRPM - 500
   IF NCMDS < 0 THEN NCMDS = 0: BEEP
3435 COLOR 14, 6
LOCATE 3, 64: PRINT " MANUAL ": PRINT
LOCATE 6, 62: PRINT USING "####.": NCMDS
GOTO 3550

3440 EM = SM - M
   IF ABS(EM) < .002 THEN FLA = 1 ELSE FLA = 0
RIM = RIMM1 + KIM * EM * DEL * KMGS
   IF RIM < -100 THEN RIM = -100
   IF RIM > 100 THEN RIM = 100
NCMDS1 = KPM * EM * KMGS + RIM + FRPM
   IF NCMDS1 > 8450 THEN NCMDS1 = 8450
   IF NCMDS1 > MAXN THEN NCMDS1 = MAXN
3550 EN = NCMDS1 - FRPM
   IF ABS(EN) < 10 THEN FLN = 1 ELSE FLN = 0
   IF ABS(EN) > 10 THEN 3560 ELSE 3570

3560 KEN = 5
GOTO 3575

3570 KEN = SQR(TT) / 20
3575 RIN = RINM1 + EN * DEL * KIN
   IF RIN > RINM1 + KEN THEN RIN = RINM1 + KEN
   IF RIN < RINM1 - KEN THEN RIN = RINM1 - KEN
   IF RIN < 0 THEN RIN = 0
   IF RIN > 6000 THEN RIN = 6000
SRPM = EN * KPN + RIN
   IF SRPM > SRPM1 + 5 THEN SRPM = SRPM1 + 5
   IF SRPM < SRPM1 - 5 THEN SRPM = SRPM1 - 5
SNRPM = SRPM / 7500
   IF SNRPM > 1 THEN SNRPM = 1
   IF SNRPM < 0 THEN SNRPM = 0
DAC(6) = SNRPM

' Fan Speed Band Warning.
   IF FRPM < 3651 THEN 3790 ELSE 3830
3790 IF FRPM > 3549 THEN 3800 ELSE 3830
3800 COLOR 20, 8
LOCATE 13, 61: PRINT " SPEED BAND ": PRINT
   BEEP
GOTO 3900
3830 COLOR 14, 6
LOCATE 13, 61: PRINT "
   PRINT

'Temperature Gradient Calculation.
3900 IW = IW + 1
   IF IW = 40 THEN 3920 ELSE 3980
3920 IF WLG > 8 THEN WLG = 0
   IF WLG < -8 THEN WLG = 0
COLOR 14, 3
LOCATE 20, 30: PRINT USING "###.###": 12 * WLG
WLG = 0
3980  IW = 0

3980  WLG = WLG + TMW1, - TMW1,1

* Liquid Back Pressure Control Loop.

\[ SLQ = \frac{SLOSC}{14.696} \]

IF FRPM < 600 THEN SLQ = 9
IF FRPM < 400 THEN SLQ = 1
IF SLQ > 10.2 THEN SLQ = 10.2

\[ SLOSC = SLQ \times 14.696 \]

\[ ELP = PLQ - SIQ \]

IF ABS(ELP) < 0.4 THEN FL5 = 1 ELSE FL5 = 0
IF ELP > 0.15 THEN ELP = 0.15
IF ELP < -0.15 THEN ELP = -0.15

\[ RIL = RLX + ELP \times KIL \times DEL \]

IF RIL < 0 THEN RIL = 0
IF RIL > 1 THEN RIL = 1

\[ ALN = KPL \times ELP + KDL \times (ELP - ELPM1) / DEL + RIL \]

IF ALN < 0 THEN ALN = 0
IF ALN > 1 THEN ALN = 1

\[ DAC(3) = ALN \]
\[ DAC(7) = 1! \]

* Screen Pressure Drop Warning.

\[ DLPC = 0.47 \times PP \times M \times M / (MF)^6 + 0.02 \]

IF DLPC > DLPC THEN FL6 = 1 ELSE FL6 = 0
IF M < 0.25 THEN FL6 = 0
IF FL6 = 1 THEN BEEP

* Controller Screen Update.

4160  JD = JD + 1

4160  IF JD = 3 THEN 4160 ELSE 4700

4160  COLOR 14, 3
4200  LOCATE 8, 26: PRINT STRINGS$(6, 0)
4200  COLOR 14, 5
4200  LOCATE 21, 47: PRINT "###.#"; PSUSCS
4240  IF AUTOE = 0 THEN 4240
4240  IF (FL3 * AUTOE) = 1 THEN 4250 ELSE 4260
4240  IF (FL3 * AUTOE) = 1 THEN 4250 ELSE 4260
4250  COLOR 14, 0
4250  LOCATE 8, 43: PRINT STRINGS$(6, 0)
4250  COLOR 14, 2

4320  COLOR 14, 0
4330  LOCATE 8, 13: PRINT STRINGS$(6, 0)
4330  COLOR 14, 6

4360  COLOR 14, 0
4370  LOCATE 8, 62: PRINT STRINGS$(6, 0)
IF (I.N-AUTOM)>0 THEN 4374 ELSE 4376
4374 COLOR 14,0
4376 LOCATE 11,62:PRINT STR$(6,000)
   COLOR 14, 3
   IF AUTOT = 1 THEN LOCATE 6, 26: PRINT USING "####.#"; ST
   LOCATE 9, 26: PRINT USING "####.#"; TT
   LOCATE 10, 26: PRINT USING "####.#"; TMWL.
   I.Q = AI.Q * 100
   LOCATE 12, 26: PRINT USING "####.#"; I.Q
   COLOR 14, 5
   LOCATE 9, 42: PRINT USING "#####"; PPUSCS
   GV1 = AGV1 * 100
   LOCATE 12, 43: PRINT USING "#####"; GV1
   GV2 = AGV2 * 100
   LOCATE 13, 43: PRINT USING "#####"; GV2
   LOCATE 10, 42: PRINT USING "#####"; RE
   COLOR 14, 6
   LOCATE 9, 62: PRINT USING ".###."; M
   LOCATE 10, 62: PRINT USING ".###."; FRPM
   LOCATE 12, 62: PRINT USING "###.#"; SNRPM * 100
   JD = 0
4700 GOSUB 7000

'Program Timing Counter.
K = K + 1
   IF K = 600 THEN BEEP ELSE 4800
   K = 0

'Setting Previous Cycle Values.
4800 AGVIP = AGV1
   AIQP = AI.Q
   ELPM1 = EL.P
   EPM2 = EPM1
   EPM1 = EP
   ETM2 = ETM1
   ETM1 = ET
   RILM1 = RIL
   RIMM1 = RIM
   RINM1 = RIN
   RIPM1 = RIP
   RITM1 = RIT
   SRPM1 = SRPM
   STP = ST
   GOTO 1000

'Controller Input Subroutine.
5000 A$ = INK$S
   IF A$ = "" THEN 5999
   IF A$ = "Q" OR A$ = "q" THEN 7500
   IF A$ = "E" OR A$ = "e" THEN 6000
   IF A$ = "D" OR A$ = "d" THEN 5950
   IF XX > 5 THEN XX = 5
   IF A$ = CHR$(13) THEN 5008 ELSE 5009
5008 IF XX = 5 THEN 5600 ELSE 5999
5009 IF J > 0 THEN 5010 ELSE 5014
5010 IF A$ = "0" OR A$ = "1" OR A$ = "2" OR A$ = "3" OR A$ = "4" OR A$ = "5" OR A$
= "G" OR A$ = "7" OR A$ = "8" OR A$ = "9" OR A$ = "." THEN 5100 ELSE 5999

COLOR 16, 3
IF A$ = "I" OR A$ = "I" THEN J = 1: LOCATE 15, 36: PRINT ",K": PRINT ;
IF A$ = "L" OR A$ = "L" THEN J = 5: LOCATE 16, 36: PRINT ",opn": PRINT ;
COLOR 16, 5
IF A$ = "R" OR A$ = "R" THEN J = 4: LOCATE 16, 54: PRINT ",miln": PRINT ;
IF A$ = "G" OR A$ = "G" THEN J = 6: LOCATE 17, 54: PRINT ",opn": PRINT ;
IF A$ = "C" OR A$ = "C" THEN J = 8: LOCATE 18, 54: PRINT ",in": PRINT ;
COLOR 16, 6
IF A$ = "M" OR A$ = "m" THEN J = 3: LOCATE 15, 71: PRINT ",Mach": PRINT ;
IF A$ = "N" OR A$ = "n" THEN J = 7: LOCATE 16, 71: PRINT ",rpm": PRINT ;
COLOR 16, 2
IF A$ = "B" OR A$ = "b" THEN J = 9: LOCATE 15, 19: PRINT ",psi": PRINT ;

IF J = 1 THEN 5105
IF J = 2 THEN 5405
IF J = 3 THEN 5205
IF J = 4 THEN 5405
IF J = 5 THEN 5405
IF J = 6 THEN 5405
IF J = 7 THEN 5350
IF J = 8 THEN 5405
IF J = 9 THEN 5105

GOTO 5999

'Assemble Temperature and Liquid Back Pressure Inputs.
5105  XX = XX + 1
D1 = 1: D2 = 2: D3 = 3: D4 = 4: D5 = 5
GOSUB 5500
AA = H1 * 100 + H2 * 10 + H3 + H5 / 10
GOTO 5999

'Assemble Mach Number Input.
5205  XX = XX + 1
D1 = 1: D2 = 3: D3 = 4: D4 = 2: D5 = 5
GOSUB 5500
AA = H2 / 10 + H3 / 100 + H5 / 1000
GOTO 5999

'Assemble Fan Speed Input.
5305  XX = XX + 1
D1 = 1: D2 = 2: D3 = 3: D4 = 5: D5 = 4
GOSUB 5500
AA = H1 * 1000 + H2 * 100 + H3 * 10 + H5
GOTO 5999
'Assemble Pressure, Reynolds Number, Injection Valve, Exhaust Valve, and Chord Inputs.

5405 \[ XX = XX + 1 \]
\[ D1 = 1; D2 = 2; D3 = 4; D4 = 3; D5 = 5 \]
GOSUB 5500
\[ AA = H1 * 10 + H2 + H3 / 10 + H5 / 100 \]
GOTO 5999

5500
IF \( J = 1 \) THEN COLOR 0, 3
IF \( J = 2 \) THEN COLOR 0, 5
IF \( J = 3 \) THEN COLOR 0, 6
IF \( J = 4 \) THEN COLOR 0, 7
IF \( J = 5 \) THEN COLOR 0, 8
IF \( J = 6 \) THEN COLOR 0, 9
IF \( J = 7 \) THEN COLOR 0, 10
IF \( J = 8 \) THEN COLOR 0, 11
IF \( J = 9 \) THEN COLOR 0, 12
IF \( XX = 1 \) THEN H1 = VAL(A$): LOCATE LU, MU + D1: PRINT USING ";##0":H1
IF \( XX = 2 \) THEN H2 = VAL(A$): LOCATE LU, MU + D2: PRINT USING ";##0":H2
IF \( XX = 3 \) THEN H3 = VAL(A$): LOCATE LU, MU + D3: PRINT USING ";##0":H3
IF \( XX = 4 \) THEN H4 = VAL(A$): LOCATE LU, MU + D4: PRINT CHR$(46):
IF \( XX = 5 \) THEN H5 = VAL(A$): LOCATE LU, MU + D5: PRINT USING ";##0":H5
RETURN

'Set Temperature Input.

5600
IF \( J = 1 \) THEN 5620 ELSE 5660
5620
\[ ST1 = AA \]
IF \( ST1 > MAXT \) THEN \( ST1 = MAXT \)
IF \( ST1 < MINT \) THEN \( ST1 = MINT \)
\[ STP = "\" \]
COLOR 14, 3
LOCATE 3, 29: PRINT " AUTO ": PRINT;
AUTOT = 1
LOCATE 5, 26: PRINT USING "###.#": ST1

'Set Pressure Input.

5660
IF \( J = 2 \) THEN 5670 ELSE 5730
5670
\[ SP = AA \]
IF \( SP < MINP \) THEN \( SP = MINP \)
IF \( SP > MAXP \) THEN \( SP = MAXP \)
COLOR 14, 5
LOCATE 3, 46: PRINT " AUTO ": PRINT;
LOCATE 6, 43: PRINT " AUTO ": PRINT;
LOCATE 5, 43: PRINT USING "##.##": SP
AUTOP = 1
AUTORE = 0

'Set Mach Number Input.

5730
IF \( J = 3 \) THEN 5740 ELSE 5750
5740
\[ SM = AA \]
IF \( SM < MINM \) THEN \( SM = MINM \)
IF \( SM > MAXM \) THEN \( SM = MAXM \)
COLOR 14, 6
LOCATE 3, 64: PRINT " AUTO ": PRINT;
LOCATE 6, 62: PRINT " AUTO ": PRINT;
AUTOM = 1
LOCATE 5, 62: PRINT USING "#.###"; SM

'Set Reynolds Number Input.
5750 IF J = 4 THEN 5760 ELSE 5770
5760 SRE = AA
   IF SRE > MAXRE THEN SRE = MAXRE
   IF SRE < MINRE THEN SRE = MINRE
COLOR 14, 5
AUTORE = 1
AUTOP = 1
LOCATE 6, 43: PRINT USING "##.##"; SRE
LOCATE 3, 46: PRINT " AUTORE ": PRINT ;

'Set Liquid Injection Valve Input.
5770 IF J = 5 THEN 5780 ELSE 5810
5780 LCMDS = AA
COLOR 14, 3
LOCATE 3, 29: PRINT " MANUAL ": PRINT ;
LOCATE 5, 26: PRINT " 
LOCATE 6, 26: PRINT " 
AUTOT = 0

'Set Gas Exhaust Valve Input.
5810 IF J = 6 THEN 5820 ELSE 5860
5820 GMCDS = AA
COLOR 14, 5
LOCATE 3, 46: PRINT " MANUAL ": PRINT ;
AUTOP = 0
AUTORE = 0
LOCATE 5, 43: PRINT " ": PRINT ;
LOCATE 6, 43: PRINT " ": PRINT ;

'Set Fan Speed Input.
5860 IF J = 7 THEN 5870 ELSE 5935
5870 NCMDS = AA
   IF NCMDS > MAXN THEN NCMDS = MAXN
COLOR 14, 6
LOCATE 5, 62: PRINT " 
LOCATE 3, 64: PRINT " MANUAL ": PRINT ;
LOCATE 6, 62: PRINT USING "####. "; NCMDS
AUTOM = 0

'Set Chord Length Input.
5935 IF J = 8 THEN 5937 ELSE 5943
5937 CHIN = AA
   IF CHIN < MINCHIN THEN CHIN = MINCHIN
   IF CHIN > MAXCHIN THEN CHIN = MAXCHIN
COLOR 14, 5
LOCATE 20, 48: PRINT USING "##.##"; CHIN
CHI = CHIN * .0254

'Set Liquid Back Pressure Input.
5943 IF J = 9 THEN 5944 ELSE 5950
5944 SIQSC = AA
   IF SIQSC > MAXLIQSC THEN SIQSC = MAXLIQSC
COLOR 14, 2
LOCATE 5, 13: PRINT USING "##.##"; SIQSC

46
5950 IF J = 0 THEN 5962.
5960 IF J = 1 THEN COLOR 14, 3
5961 IF J = 2 THEN COLOR 14, 5
5962 IF J = 3 THEN COLOR 14, 6
5963 IF J = 4 THEN COLOR 14, 5
5964 IF J = 5 THEN COLOR 14, 3
5965 IF J = 6 THEN COLOR 14, 5
5966 IF J = 7 THEN COLOR 14, 6
5967 IF J = 8 THEN COLOR 14, 5
5968 IF J = 9 THEN COLOR 14, 2
5969 LOCATE 1, U, MU + 1: PRINT "*: PRINT ;
5970 IF J > 0 THEN BEEP
5971 IF IE = 1 THEN COLOR 0, 6
5972 IF IE = 1 THEN BEEP: LOCATE 20, 60: PRINT "*: PRINT ;
5973 IF PIE = 1 THEN LOCATE 21, 60: PRINT "*: PIE = 0
5974 IF NIE = 1 THEN LOCATE 21, 60: PRINT "*: NIE = 0
5975 J = 0
5976 XX = 0
5977 IE = 0
5978 RETURN

0000 IE = 1
0001 COLOR 20, 8
0002 LOCATE 20, 60: PRINT "EMERGENCY STOP ": PRINT ;
0003 COLOR 4, 8
0004 IF PIE = 1 THEN LOCATE 21, 60: PRINT "Pressure Limit 
0005 IF NIE = 1 THEN LOCATE 21, 60: PRINT "Fan RPM Limit 
0006 COLOR 4, 8
0007 AUTOT = 0
0008 AUTOP = 0
0009 AUTOM = 0
0010 AUTORE = 0
0011 LOCATE 3, 29: PRINT "MANUAL ": PRINT ;
0012 LOCATE 3, 46: PRINT "MANUAL ": PRINT ;
0013 LOCATE 3, 64: PRINT "MANUAL ": PRINT ;
0014 RETURN

0700 WG = 4375 * PP / TT
0701 WT = 3200!
0702 CM = (5.5 * 'TT' - .008 * 'TT' ^ 2) / 1000
0703 CP = 1.04
0704 CV = .75
0705 TMC = .28 * 'TT' ^ 1.2 / PP ^ .7 / M ^ 2
0706 LMFL = ALQ * LF
0707 GMFL = (AGV1 + AGV2) * CGV * 2.725 * PP / SQR(TT)
0708 IF PP < 1.5 THEN GMFL = (AGV1 + AGV2) * PP / SQR(TT) * 21.8 * (2 - (1.5 / PP) ^ 1.7)
0709 WLT = (TMWL - 'TT') * WT * CM / TMC
0710 HEAT = WLT + FKW - LMFL * (121 + CV * 'TT') - GMFL * (CP - CV) * 'TT'
0711 DPP = DEL * PP + HEAT / 'TT' / WG / CV + DEL * (LMFL - GMFL) * PP / WG
0712 PPN = PP + DPP
0713 IF PPN > 6! THEN PPN = 6!
0714 IF PPN < 1! THEN PPN = 1!
TMWL = (DEL / (2 * TMC + DEL)) * (TT + TT1) + ((2 * TMC - DEL) / (2 * TMC + DEL)) * TMW1
DFR1 = (1 / (DEL ^ 2 + 1.12 * DEL + .8))
DFR2 = (DEL ^ 2) * (SRPM + SRPM1 * 2 + SRPM2) - FRPM * (2 * DEL ^ 2 - 1.6)
DFR3 = DFR2 - FRPM1 * (DEL ^ 2 - 1.12 * DEL + .8)
FRPMN = DFR1 * DFR3
DTT = DEL * HEAT / WG / CV
TTN = TT + DTT
ALF1 = (ALN - .2) * 5
PLQ = 7.3 + ALF1 * 3 + ALQ * .7
PLQN = DEL / (2 + DEL) * (PLO + PLO1) + (2 - DEL) / (2 + DEL) * PLQ
IF PLQN < 7.3 THEN PLQN = 7.3
PP1 = PP
TT1 = TT
TMW1.1 = TMW1.
FRPM1 = FRPM
SRPM2 = SRPM1
PLO1 = PLO
TT = TTN
IF TT < SAT1 THEN TT = SAT1
PP = PPN
TMWL = TMWL.
FRPM = FRPMN
PLQ = PLQN
RETURN

7500 CLS
SYSTEM
Appendix C
Source Code Variables

Limits Input Keyboard Commands

A,a  Accepts the tunnel maximum-minimum limits and starts the 0.3-m TCT controller.

D,d  Delete the previous input keys shown on the screen and not yet executed.

M,m  Input maximum Mach number limit. Maximum Mach number limit format is #.###, range to 0.15 to 0.995.

N,n  Input maximum fan speed limit. Maximum fan speed limit format is ####., range is 0 to 5600 rpm.

P,p  Input maximum tunnel total pressure limit. Maximum tunnel total pressure limit format is ##.##, range is 14.7 to 88.0 psia.

R,r  Input maximum Reynolds number limit. Maximum Reynolds number limit format is ##.##, range is 1 to 50 million.

S,s  Accepts the user set maximum-minimum limits and starts the 0.3-m TCT controller.

T,t  Input minimum temperature limit. Minimum temperature limit format is ###.#, range is 77 to 340 K.

Controller Input Keyboard Commands

B,b  Input LN2 back pressure set point. LN2 back pressure set point format is ###.#, range is LN2 pressure to 150 psia.

C,c  Input mean aerodynamic chord. Chord format is ##.##, range is 0.39 to 15.75 inches.

D,d  Delete the previous input keys memorized on the screen and not yet executed.

G,g  Input GN2 discharge valve area. Takes the pressure controller and Reynolds number controller to manual control mode. GN2 discharge valve area format is ##.##, range is 99.99%=full open to 0%=closed.

L,l  Input LN2 injection valve area. Takes the temperature controller to manual control mode. LN2 injection valve area format is ##.##, range is 99.99%=full open to 0%=closed.
M, m Input Mach number set point. Takes fan speed to automatic Mach number control mode. Mach number set point format is #.###, range is 0.150 to 0.995.

N, n Input fan speed set point. Takes the fan speed to manual Mach number control mode. Fan speed set point format is ####., range is 0 to 5600 rpm.

P, p Input tunnel total pressure set point. Takes the controller to automatic pressure control mode and manual Reynolds number control mode. Total pressure set point format is ##.##, range is 14.7 to 88 psia.

R, r Input Reynolds number set point. Takes the pressure controller to automatic Reynolds number control mode by generating the required pressure set point. Reynolds number set point format is ##.##, range is 1 to 50 million.

T, t Input temperature set point. Takes the controller to automatic temperature control mode. Temperature set point format is ###.#, range is saturation temperature to 340 K.

Program Variables

AA Keyboard input function. Combines the integer inputs H1, H2, H3, and H5 with proper decimal scaling for use in program calculation.

AEMP Temporary data register output in digital to analog conversion routine to check status.

AGV1 Area of GN1 discharge valve #1. Full open AGV1=1 and closed AGV1=0. AGV1=KPGS*(KPP*EP+KDP*(EP-2*EPM1+EPM2/2/DEL)+RIP

AGV1P Area of GN1 discharge valve #1, previous cycle value.

AGV2 Area of GN2 discharge valve #2. Full open AGV2=1 and closed AGV2=0. Valve #2 opens only when AGV1 > 90% open and starts closing when AGV1 < 70% open. Valve #2 moves at a rate of 1% per cycle.

ALF1 Simulator variable. Variable related to the area of LN2 back pressure valve used in calculating the estimated LN2 back pressure. ALF1=(ALN-2)*5

ALN Area of LN2 back pressure control valve. Full open ALN=1 and closed ALN=0. ALN=KPL*ELP+KDL*(ELP-ELPM1)*DEL+RIL

ALQ Area of LN2 injection valve. Full open ALQ=1 and closed ALQ=0. ALQ=KTGS*(KPT*ET+KDT*(ET-2*ETM1+ETM2)/2/DEL)*RIT+FBF

ALQP Area of LN2 injection valve, previous cycle value.
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUTOM</td>
<td>Mach number controller: AUTOM=1 automatic Mach number control. AUTOM=0 manual Mach number control.</td>
</tr>
<tr>
<td>AUTOP</td>
<td>Pressure controller: AUTOP=1 automatic pressure control. AUTOP=0 manual pressure control.</td>
</tr>
<tr>
<td>AUTORE</td>
<td>Reynolds number controller: AUTORE=1 automatic Reynolds number control. AUTORE=0 manual Reynolds number control.</td>
</tr>
<tr>
<td>AUTOT</td>
<td>Temperature controller: AUTOT=1 automatic temperature control. AUTOT=0 manual temperature control.</td>
</tr>
<tr>
<td>A$</td>
<td>Input variable from the keyboard buffer.</td>
</tr>
<tr>
<td>BEMP</td>
<td>Temporary status register output in digital to analog conversion routine to check status.</td>
</tr>
<tr>
<td>BSD</td>
<td>Dummy calculation to create a time delay between resetting the digital to analog conversion and reading its status. Used only during initialization of digital to analog conversion.</td>
</tr>
<tr>
<td>B$</td>
<td>Input variable from the keyboard buffer.</td>
</tr>
<tr>
<td>CEMP</td>
<td>Temporary status register output in digital to analog conversion subroutine.</td>
</tr>
<tr>
<td>C$</td>
<td>Input variable from the keyboard buffer.</td>
</tr>
<tr>
<td>CGV</td>
<td>Coefficient for GN₂ exhaust valve.</td>
</tr>
<tr>
<td>CH</td>
<td>Aerodynamic chord in meters.</td>
</tr>
<tr>
<td>CHIN</td>
<td>Aerodynamic chord in inches. Loaded through the keyboard using the &quot;C&quot; command. Default value is CHIN=0.1800*0.0254.</td>
</tr>
<tr>
<td>CLQV</td>
<td>Flow coefficient of LN₂ injection valve.</td>
</tr>
<tr>
<td>CM</td>
<td>Simulator variable. Specific heat of tunnel metal. CM=(5.5<em>TT-0.008</em>TT²)/1000</td>
</tr>
<tr>
<td>CP</td>
<td>Simulator variable. Specific heat of nitrogen at constant pressure.</td>
</tr>
<tr>
<td>CRPM</td>
<td>Simulator variable. Fan speed in rpm with a minimum limit of 50 rpm.</td>
</tr>
</tbody>
</table>
CRM  *Simulator variable.*  Variable used in calculating Mach number as a function of fan speed, pressure, and temperature.
\[ CRM = 2.77 - \frac{CRPM}{157} \sqrt{T} \times PP^{0.035} \]

CV  *Simulator variable.*  Specific heat of nitrogen at constant volume.

DAC(1) Control variable ALQ output.

DAC(2) Control variable ALQ output.

DAC(3) Control variable ALN output.

DAC(4) Control variable AGV1 output.

DAC(5) Control variable AGV2 output.

DAC(6) Control variable SNRPM output.

DAC(7) RPM/MACH controller output for rheostat control. DAC(7)=1 for normal operation. DAC(7)=0 for rheostat control.

D1 Integer used to print properly the variable being loaded through the keyboard.

D2 Integer used to print properly the variable being loaded through the keyboard.

D3 Integer used to print properly the variable being loaded through the keyboard.

D4 Integer used to print properly the variable being loaded through the keyboard.

D5 Integer used to print properly the variable being loaded through the keyboard.

DEL Cycle time step.

DFR1  *Simulator variable.*  Variable used in calculating the estimated fan speed rpm.
\[ DFR1 = \frac{1}{\left(1 + 1.12 \times DEL + 0.8\right)} \]

DFR2  *Simulator variable.*  Variable used in calculating the estimated fan speed rpm.
\[ DFR2 = \left(DEL^2 + \left(SRPM + SRPM1 + SRPM2\right) - FRPM\right) \times \left(2 + DEL^2 - 1.6\right) \]

DFR3  *Simulator variable.*  Variable used in calculating the estimated fan speed rpm.
\[ DFR3 = DFR2 - FRPM \times \left(DEL^2 - 1.12 \times DEL + 0.8\right) \]

DLP Difference in pressure across the screens of the tunnel settling chamber, (psia).
**DLPC**

Maximum safe screen pressure drop allowed.

\[ DLPC = 0.47 \times PP \times M^2 \times (MF)^6 + 0.02 \]

**DPP**

Simulator variable. Estimated change in tunnel total pressure for one cycle.

\[ DPP = \text{DEL} \times PP \times \text{IEAT} \times \text{WG/CV} + \text{DEL} \times (\text{LMFL} - \text{GMFL}) \times PP \times \text{WG} \]

**DRPM**

Fan speed in rpm with a minimum limit of 100 rpm.

**DR1**

Command output high integer buffer in digital to analog conversion routine, (12 bit).

**DR2**

Command output low integer buffer in digital to analog conversion routine, (4-bit).

**DTT**

Simulator variable. Estimated change in tunnel temperature for one cycle.

\[ DTT = \text{DEL} \times \text{HEAT} \times \text{WG/CV} \]

**ELP**

Error in LN pressure control, (atm).

\[ ELP = SLQ - PLQ \]

**ELPM1**

Error in LN pressure control, previous cycle value.

**EM**

Error in Mach number control.

\[ EM = SM - M \]

**EN**

Error in fan speed control, (rpm).

\[ EN = \text{NCMDS1} - \text{FRPM} \]

**EP**

Error in total pressure control, (atm).

\[ EP = PP - \text{SPR} \]

**EPM1**

Error in total pressure control, previous cycle value.

**EPM2**

Error in total pressure control, twice previous cycle value.

**ET**

Error in temperature control, (kelvin).

\[ ET = \text{TT} - \text{ST} \]

**ETM1**

Error in temperature control, previous cycle value.

**ETM2**

Error in temperature control, twice previous cycle value.

**E(1)**

Input millivolts from total pressure sensor.

**E(2)**

Input millivolts from static pressure sensor.

**E(3)**

Input millivolts from total temperature thermocouple.

**E(4)**

Input millivolts from the tunnel metal wall temperature thermocouple.

**E(5)**

Input millivolts from fan speed sensor.
E(6) Input millivolts from LN\textsubscript{2} pressure transducer.

E(7) Input millivolts from the screen pressure drop transducers.

E11 Output from analog to digital conversion of the tunnel total pressure for monitor display.

E12 Output from analog to digital conversion of the tunnel static pressure for monitor display.

FB Fan bias, an equivalent of FKW in LN\textsubscript{2} flow. \( FB = FKW/(121+TT)/LF \)

FBF Product of FB and FF. \( FBF = FB \times FF \times 0.8 \)

FF Feed forward logic integer. \( FF = 1 \) the fan bias is fed forward as LN\textsubscript{2}, \( FF = 0 \) the fan bias is not fed forward as LN\textsubscript{2}. The feed forward is off during tunnel warm-ups.

FKM Variable used in calculating the tunnel fan speed/test section coupling. \( FKM = 1 - 0.5 \times M \)

FKW Estimated fan power released to gas, (kilowatts). \( FKW = 100 \times PP \times (FRPM/1000)^{2.26} / \text{SQR(TTMP)} \)

FL0 Logic flag. \( FL0 = 1 \) when the set limit maximum equals the tunnel minimum value. This condition is an unacceptable condition to run the tunnel controller. \( FL0 = 0 \) corresponds to acceptable tunnel set limits to run the tunnel controller.

FL1 Logic flag. \( FL1 = 1 \) when the error in the temperature control is less than 0.3 K. \( FL1 = 0 \) corresponds to a larger temperature control error.

FL2 Logic flag. \( FL2 = 1 \) when metal temperature is within 24 K of the tunnel temperature set point. \( FL2 = 0 \) corresponds to a larger temperature difference. \( FL1 \times FL2 = 1 \) corresponds to the temperature of the tunnel at the temperature set point.

FL3 Logic flag. \( FL3 = 1 \) when the error in pressure control is less than 0.005 atm. \( FL3 = 0 \) corresponds to a larger pressure control error.

FL4 Logic flag. \( FL4 = 1 \) when the error in Mach number is less than 0.002. \( FL4 = 0 \) corresponds to a larger Mach number control error.

FL5 Logic flag. \( FL5 = 1 \) when the error in the LN\textsubscript{2} back pressure control is less than 0.4 atm. \( FL5 = 0 \) corresponds to a larger LN\textsubscript{2} back pressure error.
FL6 Logic flag. FL6=1 when the pressure difference across the tunnel screens is unsafe. FL6=0 corresponds to a safe pressure difference.

FL7 Logic flag. FL7=1 when the error in the Reynolds number control is less than 0.05. FL7=0 corresponds to a larger Reynolds number control error.

FL10 Logic flag. FL10=1 when a sensor fails. FL10=0 corresponds to normal operation. A sensor failure will cause an emergency stop.

FRPM Fan speed in rpm.

FRPMN Simulator variable. Estimated fan speed. FRPMN=DFR1*DFR3

GCMDS GN2 discharge valve area. Loaded through the keyboard using the "G" command.

GF1 Mass flow from the tunnel. GF1=2.725*CGV*PP/SQR(TT)

GMFL Simulator variable. GN2 exhaust mass flow.

GV1 Product of AGV1 and 100. GV1=AGV1*100

GV2 Product of AGV2 and 100. GV2=AGV2*100

H1 First integer of an input keyed during a variable input.

H2 Second integer of an input keyed during a variable input.

H3 Third integer of an input keyed during a variable input.

H5 Fourth integer of an input keyed during a variable input.

HEAT Simulator variable. The total heat flow of the tunnel.

HEAT=WLHT+FKW-LMFL*(121+CV*TT)-GMFL*(CP-CV)*TT

HI High byte to digital to analog conversion buffer of the digital to analog conversion routine.

I Integer cycle counter used to display the controller screen borders.

IE Logic flag. IE=1 corresponds to an emergency stop. IE=0 corresponds to normal operation.

IK Integer cycle counter used for output of digital to analog conversion variables.

IW Integer cycle counter for integrating the wall temperature gradient.
J  Integer variable that identifies the input variables.
JD  Integer cycle counter for displaying certain variables on the screen.
JJ  Integer cycle counter for calculation of BSD.
K  Simulator variable. Integer cycle counter for a 600 cycle beep.
KDL  LN₂ back pressure control derivative gain.
KDP  Pressure control derivative gain.
KDT  Temperature control derivative gain.
KEN  A gradient term limiting the rpm of the fan speed.
KIL  LN₂ back pressure control integral gain.
KIM  Mach number control integral gain.
KIN  Fan speed control integral gain.
KIP  Pressure control integral gain.
KIT  Temperature control integral gain.
KMC  Constant corresponding to tunnel fan speed/test section coupling in the Mach number controller. KMC=520*SQR(TT)*FKM/PP^0.035
KMGS  Mach number control gain schedule function. KMGS=KMC*KMM
KMM  Mach number control gain.
KP  Pressure control gain.
KPGS  Pressure control gain schedule function. KPGS=750*KP/PP/SQR(TT)
KPL  LN₂ back pressure control proportional gain. KPL=0.2
KPM  Mach number control proportional gain.
KPN  Fan speed control proportional gain.
KPP  Pressure control proportional gain.
KPT  Temperature control proportional gain.
KRE  Constant used for evaluating Reynolds number related functions.
  KRE=63714*CH*M/TT^1.4*(MF)^2.1

KT   Temperature control gain factor.

KTGS Temperature control gain schedule function.
  KTGS=DRPM*SQR(PP)*KT/3.0/TT/LF

LC   Screen column number used in LOCATE statements.

LCMDS LN₂ valve area. Loaded through the keyboard using the "L" command.

LDPO Difference between LN₂ back pressure and tunnel pressure.
  LDPO=PLQ-PP

LF   LN₂ flow when LN₂ injection valve is full open.
  LF=CLQV*0.8676*SQR(LDPO)

LMFL Simulator variable. LN₂ injected mass flow. LMFL=ALQ*LF

LMT  Limiter for LN₂ flow. LMT=1-(TMWL-TT-MXT/2)*2/MXT

LO   An output driving the digital to analog conversion low buffer for final
     command. Low byte data register in digital to analog conversion routine.

LQ   Product of ALQ and 100. LQ=ALQ*100

LR   Screen row number used in LOCATE statements.

LU   Screen column number used in LOCATE statements.

M    Tunnel flow Mach number in the test section based on the difference
     between total and static pressure.

MAXCH Maximum aerodynamic chord length limit in meters.

MAXCHIN Maximum aerodynamic chord length limit in inches.

MAXLQSC Tunnel maximum LN₂ back pressure.

MAXM  User set maximum Mach number limit. Must be less than MAXM1.

MAXM1 Tunnel maximum Mach number limit.

MAXN  User set maximum fan speed limit. Must be less than MAXN1.
MAXN1  Tunnel maximum fan speed limit.
MAXP   User set maximum pressure limit. Must be less than MAXP1.
MAXP1  Tunnel maximum pressure limit.
MAXRE  User set maximum Reynolds number limit. Must be less than MAXRE1.
MAXRE1 Tunnel maximum Reynolds number limit.
MAXSPR1 Maximum pressure set point estimated from the Reynolds number set point. Valid in automatic Reynolds number control. \( \text{MAXSPR1} = \text{MAXP1}/14.696 \)
MAXT   Maximum temperature limit.
MAXT1  Tunnel maximum temperature limit.
MF     Isentropic function of the tunnel flow Mach number. \( \text{MF} = (1 + 0.2 \times M \times M) \)
MINCH  Minimum aerodynamic chord length in meters.
MINCHIN Minimum aerodynamic chord length in inches.
MINM   Minimum Mach number limit.
MINM1  Tunnel minimum Mach number limit.
MINN   Minimum fan speed limit.
MINN1  Tunnel minimum fan speed limit.
MINP   Minimum pressure limit.
MINP1  Tunnel minimum pressure limit.
MINRE  Minimum Reynolds number limit.
MINRE1 Tunnel minimum Reynolds number limit.
MINSPR1 Minimum pressure set point estimated from the Reynolds number set point. Valid in automatic Reynolds number control mode. \( \text{MINSPR1} = \text{MINP1}/14.696 \)
MINT   User set minimum temperature limit. Must be greater than MINT1.
MINT1  Tunnel minimum temperature limit.
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MU</td>
<td>Screen column number used in the LOCATE statements.</td>
</tr>
<tr>
<td>MXT</td>
<td>Maximum safe temperature difference allowed between tunnel gas and tunnel metal wall.</td>
</tr>
<tr>
<td>NCMDS</td>
<td>Fan speed set point. Loaded through the keyboard using the &quot;N&quot; command.</td>
</tr>
<tr>
<td>NCMDS1</td>
<td>Fan speed set point derived from NCMDS or other safety fan speed commands.</td>
</tr>
<tr>
<td>NIE</td>
<td>Logic flag. NIE=1 when the tunnel exceeds the fan speed rpm limit. NIE=1 will cause an emergency stop of the tunnel. NIE=0 corresponds to normal operation.</td>
</tr>
<tr>
<td>PIE</td>
<td>Logic flag. PIE=1 when the tunnel exceeds the total pressure limit. PIE=1 will cause an emergency stop of the tunnel. PIE=0 corresponds to normal operation.</td>
</tr>
<tr>
<td>PLO</td>
<td>Simulator variable. Variable used in calculating the estimated LN$_2$ back pressure. PLO=7.3+ALFI<em>3+ALQ</em>.7</td>
</tr>
<tr>
<td>PLO1</td>
<td>Simulator variable. Variable used in calculating the estimated LN$_2$ back pressure, previous cycle value.</td>
</tr>
<tr>
<td>PLQ</td>
<td>LN$_2$ back pressure, (atm).</td>
</tr>
<tr>
<td>PLQN</td>
<td>Simulator variable. Estimated LN$_2$ back pressure. PLQN=DEL/(2+DEL)*(PLO+PLO1)+(2-DEL)/(2+DEL)*PLQ</td>
</tr>
<tr>
<td>PLQUSCS</td>
<td>LN$_2$ back pressure, (psia). PLQUSCS=PLQ*14.696</td>
</tr>
<tr>
<td>PP</td>
<td>Tunnel total pressure, (psia).</td>
</tr>
<tr>
<td>PPN</td>
<td>Simulator variable. Estimated tunnel total pressure. PPN=PP+DPP</td>
</tr>
<tr>
<td>PP1</td>
<td>Simulator variable. Tunnel total pressure, previous cycle value.</td>
</tr>
<tr>
<td>PPUSCS</td>
<td>Tunnel total pressure, (psia). PPUSCS=PP*14.696</td>
</tr>
<tr>
<td>PS</td>
<td>Static pressure, (atm).</td>
</tr>
<tr>
<td>PSUSCS</td>
<td>Static pressure, (psia). PSUSCS=PS*14.696</td>
</tr>
<tr>
<td>RE</td>
<td>Flow Reynolds number based on aerodynamic chord. RE=KRE*PP</td>
</tr>
<tr>
<td>READ.WAIT</td>
<td>Digital to analog software read command.</td>
</tr>
</tbody>
</table>

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RIL  LN₂ back pressure control integral error, (atm-sec).
    RIL=RILM₁+ELP*KIL*DEL

RILM₁  LN₂ back pressure control integral error, previous cycle value.

RIM  Mach number control integral error, (Mach-sec).
    RIM=RIMM₁+KIM*EM*DEL*KMGS

RIMM₁  Mach number control integral error, previous cycle value.

RIN  Fan speed control integral error, (rpm-sec).
    RIN=RINM₁+EN*DEL*KIN

RINM₁  Fan speed control integral error, previous cycle value.

RIP  Tunnel total pressure control integral error, (atm-sec).
    RIP=RIPM₁+EP*KPGS*KIP*DEL

RIPM₁  Tunnel total pressure control integral error, previous cycle value.

RIT  Temperature control integral error, (K-sec).
    RIT=RITM₁+KIT*KTGS*DEL*ET

RITM₁  Temperature control integral error, previous cycle value.

SAT  Nitrogen saturation temperature based on Jacobsen's data.
    SAT=50+27.34*PS^0.296

SAT₁  Nitrogen saturation temperature applied to tunnel static pressure.
    SAT₁=SAT*MF

SLQ  LN₂ back pressure control set point, (atm).
    SLQ=SLQSC/14.696

SLQSC  LN₂ back pressure set point. Loaded through the keyboard using the "B" command.

SM  Mach number set point. Loaded through the keyboard using the "M" command.

SNRPM  Fan speed rheostat drive command normalized to one.
    SNRPM=SRPM/7500

SP  Tunnel total pressure set point. Loaded through the keyboard using the "P" command.

SPR  Tunnel total pressure set point, (atm).
    SPR=SP/14.696

SPR₁  Tunnel total pressure set point estimated from the Reynolds number set point.
    Valid in automatic Reynolds number control mode.
    SPR₁=SRE/KRE
SPRU  Tunnel total pressure set point estimated from the Reynolds number set point, (psia). SPRU=SPR*14.696

SRE  Reynolds number set point. Loaded through the keyboard using the "R" command.

SRPM  Fan speed command from control law. SRPM=EN*KPN+RIN

SRPM1  Fan speed command from control law, previous cycle value.

ST  Tunnel use temperature set point. Based on a safe temperature for given tunnel conditions. Also for conditions when both TT and PP are high and the gas mass in the tunnel is inadequate to reach the final temperature set point.

ST1  Tunnel temperature set point. Loaded through the keyboard using the "T" command, (kelvin).

STP  Tunnel use temperature set point, previous cycle value.

TMC  Simulator variable. Metal time constant of heat release. TMC=948/TT^-1.12/PP^0.8/M^0.8

TMWL  Tunnel metal wall temperature, (kelvin).

TMWLN  Simulator variable. Estimated tunnel metal wall temperature. TMWLN=(DE1^2*TMC+DE1)*(TT+TT1)+((2*TMC+DE1)/(2*TMC+DE1))*TMWL

TMWL1  Tunnel metal wall temperature, previous cycle value.

TT  Temperature of tunnel gas, (kelvin).

TTN  Simulator variable. Estimated tunnel gas temperature. TTN=TT+DTT

TTI  Simulator variable. Temperature of tunnel gas, previous cycle value.

TTMP  Temperature of tunnel gas with a minimum limit of 80 K.

WG  Simulator variable. Mass of nitrogen gas in the tunnel. WG=4375*PP/TT

WLG  Rate of change for the tunnel metal wall temperature. Wall temperature gradient. WLG=WLG+TMWL-TMWL1

WLHT  Simulator variable. Rate of heat release from the metal walls in the tunnel. WLHT=(TMWL-TT)*WT*CM/TMC

WRITE.WAIT  Digital to analog software write command.
WT  Simulator variable. Mass of the tunnel metal exposed to the tunnel flow.
XDLP  Screen pressure drop transducer sensitivity.
XFRPM  Fan speed sensor sensitivity.
XPLQ  LN$_2$ back pressure sensor sensitivity.
XPP  Tunnel total pressure transducer sensitivity.
XPS  Static pressure transducer sensitivity.
XX  Integer counter between 0 to 5. Represents the number of keyed in characters while inputting set points into the controller.
ZADIN  Analog to Digital In software command.
ZASE.ADDRESS  Sets the DT2801 series board base address.
ZATA.REGISTER  Sets the data in register and data out register.
ZCLEAR  Digital to analog software clear command.
ZDCHNL  Analog to digital conversion channel number.
ZDGAIN  Analog to digital conversion gain switch at software level.
ZEMP  Data register output for digital to analog conversion.
ZIGH  High byte of analog to digital conversion output.
ZOL#  Analog to digital conversion output normalized to 5 volts.
ZOLT#  Analog to digital conversion output as a 16 bit binary number.
ZOMMAND.REGISTER  Register for the analog to digital commands.
ZOW  Low byte of analog to digital conversion output.
ZSTOP  Defines the hex value for a stop command, ZSTOP.
ZSTATUS.REGISTER  Register for the analog to digital status.
&H1  Hex value for ZCLEAR.
&H2  Hex value for WRITE.WAIT.
&H5  Hex value for READ.WAIT
&HC  Hex value for ZADIN.
&HF  Hex value for ZSTOP.
&H2EC Base address on the PC/AT microcomputer for analog to digital conversion.
&H224 Port number on the PC/AT microcomputer for digital to analog conversion.
&H225 Port number on the PC/AT microcomputer for digital to analog conversion.
# The NASA Langley Research Center 0.3-Meter Transonic Cryogenic Tunnel Microcomputer Controller Source Code

**The 0.3-m Transonic Cryogenic Tunnel (TCT) microcomputer-based controller has been operating for several thousand hours in a safe and efficient manner. This document provides a complete listing of the source codes for the tunnel controller and tunnel simulator. Included also is a listing of all the variables used in these programs. Several changes made to the controller are described. These changes are to improve the controller ease of use and safety.**

**Subject Terms:** Cryogenic wind tunnel; Microcomputer controller

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6. **AUTHOR(S)**
   W. Allen Kilgore and S. Balakrishna

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