NASA Contractor Report 181868

THE NASA LANGLEY RESEARCH CENTER 0.3-METER TRANSONIC CRYOGENIC TUNNEL T-P/Re-M CONTROLLER MANUAL

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Contract NAS1-17919
July 1989

NASA

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia
23665-5225

(NASA-CR-181868) THE NASA LANGLEY RESEARCH CENTER 0.3-METER TRANSONIC CRYOGENIC TUNNEL T-P/Re-M CONTROLLER MANUAL (Vigyan Research Associates) 41 p CSCL 14B

N89-26869

Unclas
G3/09 0224574

Chapter details: page

List of figures:

Appendices:

Relevant Drawings:

1. LD 662971 Rheostat Position Controller.

2. LD 662972 System Interconnection.

INTRODUCTION

The 0.3-m Transonic Cryogenic Tunnel (TCT) located in Bldg. 1242 of the NASA Langley Research Center is a fan driven liquid nitrogen (LN_2) operated pressure tunnel. The tunnel is capable of operating from 15 to 85 psia stagnation pressure, tunnel temperature from about 78 to 342 K, and Mach number ranging from 0.2 to about 1.0. Since May 1988, the tunnel has been under full automatic control of a 16 bit microcomputer. This document provides the details of the electronic interface to the tunnel sensors/actuators to a 16 bit microcomputer, the tunnel control software, the simulation software, installation of the control software on the microcomputer and other particulars essential for tunnel control software maintenance. The aim of the control software is to control the 0.3-m TCT precisely to provide necessary aerodynamic testing conditions in the test section. The simulation software provides operator training capability.

MICROCOMPUTER INTERFACE TO 0.3-m TCT

The microcomputer understands the physical status of the 0.3-m TCT by a set of highly accurate analog electrical signals from the tunnel which are converted to a numerical form through an 8 channel analog to digital converter (ADC). The ADC has a resolution of 1 in 65536 corresponding to 16 bits of information. The control commands from the microcomputer are in the form of current drive in the range 4-20 mA, 0-5 VDC or 1-5 VDC. The numerical commands are generated by the microcomputer and are converted to an electrical form through an 8 channel digital to analog converter (DAC). This DAC has a resolution of 1 in 4096 corresponding to 12 bits. Appendix A gives complete list of the sensors, their ranges and names. The microcomputer receives the tunnel status information from the following measuring devices.

Tunnel stagnation pressure:

The tunnel stagnation pressure is measured at the settling chamber by a capacitance type differential pressure transducer. The output is signal conditioned by a Datametrics amplifier working on a *fixed range* to provide 0-5 VDC for 0-6.8 atm which corresponds to a *sensitivity of* 1.366 V/atm. This sensitivity is used in the tunnel control software. Any change in the transducer sensitivity *must* be reflected in the control software.

Tunnel static pressure:

The tunnel static pressure is measured at the constant area of the test section using a pitot tube with a capacitance type differential pressure transducer. The output is signal conditioned by a Datametrics amplifier working on a *fixed* range setting to provide 0-5 VDC for 0-6.8 atm which corresponds to a *sensitivity of* 1.366 V/atm. This sensitivity is used in the tunnel control software. Any change in the sensitivity *must* be reflected in the control software.

Liquid nitrogen pressure:

The LN_2 pressure is measured by a bonded strain gauge type pressure transducer excited from a floating DC supply. The bridge output is amplified by a variable gain amplifier to provide a *sensitivity of* 2.6539 VDC/atm. The output is filtered by a 10 Hz cutoff low pass amplifier. This signal sensitivity is used in the tunnel control software. Any change in this sensitivity *must* be reflected in the control software.

Tunnel gas stagnation temperature:

The tunnel gas flow stagnation temperature is measured by a copper-constantan thermocouple (TRING-25) mounted on the thermocouple ring in the settling chamber. This is made of 0.028 inch diameter fine wire which provides good response. The thermocouple output is referred to a Kaye ice point reference. The signal output at this point is from -5.587 to 2.864 mV for 74.15 to 342.15 K. This unbalanced signal is taken to a NEFF amplifier where the gain and offset are set to obtain a *signal sensitivity of* 0 VDC output at 74.15 K and 5 VDC at 342.12 K. The gain required is about 591.65 and the offset necessary is about -3.305 volts. The amplifier output filter is set to 0-10 Hz low pass setting. This signal of 0-5 VDC is used by the tunnel controller for linearization and later use in the control laws. The linearization cannot be easily changed. Hence the thermocouple calibration for 0-5 VDC *must* be maintained.

Tunnel metal wall temperature:

The tunnel wall temperature is an important sensor which provides a safe cooldown. This sensor is located at the third corner of the 0.3-m TCT on the external surface of the tunnel structure but internal to the insulation. It has been found to provide excellent average structural temperature data and control results. This is a 0.028 inch wire diameter copper-constantan thermocouple. The signal is referred to a Kaye ice point reference. The signal varies from -5.587 mV at 74.15 K to 2.864 mV at 342.12 K. This signal is signal conditioned in a NEFF amplifier with a gain of 591.65 and an offset of -3.305 volts to generate a signal *sensitivity of* 0-5 VDC for 74.15 to 342.12 K temperature. The output filter is set to 0-10 Hz low pass setting. This signal is linearized in the controller and its calibration should not be changed.

Screen pressure drop:

The screen pressure drop is an important measurement of the 0.3-m TCT. If inadvertently moisture enters the tunnel while at temperatures below 273 K, the moisture is likely to condense on the anti-turbulence screen and with flow this may damage the screen. The screen pressure drop is measured by a bonded strain gauge type pressure transducer. The transducer is excited from a DC power supply and the output is amplified. The signal *sensitivity of* 1 VDC/psid. This is used in the controller to monitor the moisture in the tunnel. Any change in the sensitivity *must* be reflected in the controller software.

Liquid nitrogen injection valves #3531 and #3533:

LN_2 is injected into the tunnel by the controller through a set of pneumatically driven diaphragm operated flow control valves. The electropneumatic converter comes with an internal power amplifier located on the body and is set to a 4-20 mA operation. The unit provides 3-15 psig output command which is power boosted before being fed to the spring loaded diaphragm. The valves work on the 100 psia air supply energy. These valves are "air to open" type and require a signal to open. The valve full open to close time is about 0.6 seconds. This speed is essential for good control of the tunnel. Any deterioration of the valve speed should be corrected. The valve calibration must be maintained at 4 mA for full close and 20 mA for full open. The microcomputer based tunnel controller generates 4-20 mA signal drive based on this calibration.

Liquid nitrogen pressure control valve #3535:

The LN_2 pumping system has a closed circuit configuration with provision to return the unused LN_2. The supply pressure is maintained by a back pressure valve in the return leg which is operated by a diaphragm driven control valve. The electropneumatic signal transducer device drives the valve and is set to close at a 4 mA signal and to fully open at a 20 mA current signal. The pump characteristics are such that at full closed condition the line pressure is about 150 psia and full open condition is 90 psia. The controller generates the 4-20 mA drive to the pressure control valve so as to maintain the line pressure constant at a set point.

Gas discharge valves #3621 and #3622:

0.3-m TCT has three remotely controlled 4 inch valves which discharge the tunnel gas. Two of these are operated by the microcomputer based tunnel controller. These valves have been modified for electrohydraulic operation using a 4 inch stroke hydraulic actuator, a 5 gpm servo valve and a position potentiometer. An analog closed loop controller provides the position control of each of these valves based on a set point command of 1 VDC for full close and 5 VDC for full open. The tunnel controller is designed based on this *sensitivity of* 1-5 VDC. Any change which affects this sensitivity *must* be avoided. The valve #3623 is not under the control of the microcomputer.

Fan speed sensor:

The fan speed is measured by an electro-optical counting system mounted on the tunnel fan shaft. The output of the photo device is brought to a Pioneer RPM signal sensor. The instrument is adjusted for CALIBRATION setting of 3.2 KHz and RANGE setting of 6.4 KHz. The output *sensitivity at this setting of* 1.280 VDC/1000 rpm of the fan shaft. This sensitivity factor is used in the tunnel control software. Any change in this sensitivity *must* be reflected in the control software.

Fan speed control:

The 0.3-m TCT is driven by a 2 pole 3 phase induction motor supplied from a variable frequency generator. The motor speed control is obtained by varying the supply frequency from 10 to 96 Hz which corresponds to 600 to 5600 rpm on the tunnel shaft. Prolonged operation of the tunnel in the speed band of 3550-3650 rpm must be avoided. The frequency control is realized by a rheostat control which adjusts the field excitation of the DC motor driving the variable frequency generator. The rheostat is driven by an instrument position servomotor. The position servo accepts a command of 0-5 VDC to provide 600-5600 rpm speed control. The DC supply to the rheostat bridge is 5 VDC. Both the bridge reference and the set point command are generated by the tunnel controller through a pair of buffer amplifiers to prevent loading the DAC unit.

MICROCOMPUTER HARDWARE AND CONNECTIONS

The microcomputer system is mounted in the 0.3-m TCT control rack. The monitor shows through the front panel and the control keyboard is located in front of the monitor. The microcomputer system is located in the rack below the monitor. The microcomputer can be accessed only by removing the blank front panel below the monitor. The microcomputer unit is powered from an uninterrupted 115 V 60 Hz supply. The two terminal boards DT 707 and DT 701-20 are located in the rear of the control rack. The terminals are wired as noted in drawing LD 662972. The details of the wiring, microcomputer, keyboard and monitor that are necessary for tunnel control operation are presented below.

Hardware:

1. Any PC/AT class microcomputer or similar clone can be used to perform as the 0.3-m TCT controller based on the software. The minimum configuration essential is that it should have a Phoenix BIOS, 512 kilobyte RAM, a 360 kilobyte or a 1.2 megabyte $5\frac{1}{4}$ inch floppy drive, a hard disk, an enhanced color graphics monitor with its drive board, and a 5060 or 101 keyboard. The microcomputer must have a minimum operating clock speed of 12 MHz.

2. The tunnel interface is through an analog to digital converter (ADC). The software is based on the Data Translation DT 2801/5716A unit. This full size personal computer card is mounted on the system board of the PC/AT through the 62 pin bus connector. To perform as a part of the tunnel controller, the DT2801/5716A jumpers *must* be set for the following.

i) Base Address	&H2EC
ii) AD conversion setting	Bipolar
iii) Input type	Floating (DI) jumpers W3-W7

The DA conversion functions, the Digital I/O functions and the clock on the DT 2801/5716A are *NOT* used in the controller operation.

3. The DT 2801/5716A ADC card *must* be connected to the terminal strip DT707 through the connector Ansley 609-5030 on the back panel of the PC/AT. The following table gives the pin connections and the signal to be connected from the tunnel data sensors and signal conditions with sensitivities discussed in the previous section.

DT2801/5716 pin #	DT707 terminal	Polarity	Transducer	Amplifier
J1-1	CH 0	+	Stagnation Pressure	Datametrics
J1-2	CH 8/0 RET	-	Stagnation Pressure	Datametrics
J1-3	CH 1	+	Static Pressure	Datametrics
J1-4	CH 9/1 RET	-	Static Pressure	Datametrics
J1-5	CH 2	+	TRING 25	NEFF
J1-6	CH 10/2 RET	-	TRING 35	NEFF
J1-7	CH 3	+	Wall Temperature	NEFF
J1-8	CH 11/3 RET	-	Wall Temperature	NEFF
J1-9	CH 4	+	Fan Speed	Pioneer
J1-10	CH 12/4 RET	-	Fan Speed	Pioneer
J1-11	CH 5	+	LN_2 Pressure	-
J1-12	CH 13/5 RET	-	LN_2 Pressure	-
J1-13	CH 6	+	Screen ΔP	-
J1-14	CH 14/6 RET	-	Screen ΔP	-

4. The DT 2815 digital to analog conversion unit is plugged into the system board in the PC/AT microcomputer through the 62 pin connector. The unit *must* be configured as follows by use of the jumpers for using it to control the 0.3-m TCT controller:

i) Base address &H224
ii) Output range Unipolar E3-E4 and E5-E6
iii) Output mode selection

Output mode selection	Jumper settings
Ch 0 - current	jumper (E28 - E36)
Ch 1 - current	jumper (E27 - E35)
Ch 2 - current	jumper (E26 - E34)
Ch 3 - voltage	jumper (E17 - E27)
Ch 4 - voltage	jumper (E16 - E24)
Ch 5 - voltage	jumper (E15 - E23)
Ch 6 - voltage	jumper (E14 - E22)
Ch 7 - not used	

5. The DAC DT2815 *must* be connected to the terminal strip DT-701-20 through two EP047 cables of eight foot length each. The connectors J1 and J2 at either end of the cable mating, the DT 2815 unit and the terminal strip are male-female pairs of 3M3421. The terminal strip

DT-701-20 is internally wired to provide a +12 VDC supply to the current outputs at pin J2-9 which carries the 12 volts supply from the computer and is *internally* wired to terminals T2, T4 and T6 of the terminal strip. The following table provides the connection details for the outputs.

DT701-20	Actuator
T1	#3531
T2	#3531
T3	#3533
T4	#3533
T5	#3535
T6	#3535
T18	#3621
T19	#3621
T42	#3622
T43	#3622
T44	Signal to rheostat servo through buffer amp (ground)
T45	+ Signal to rheostat servo through buffer amp (0-5 VDC)
T46	Same as T44
T47	Reference signal to rheostat servo (5 VDC)

6. The keyboard is altered by physically deleting a few keys from the standard 101 keyboard. These keys are Control, Alternate, Delete, Print Screen, Scroll Lock, and Pause. This can be done by removing the spring loaded key pads and blanking the area.

MICROCOMPUTER SOFTWARE

The software is available as three disks called CONTROL, SIMULATOR and BOOT. The software CONTROL alone is sufficient for operating the 0.3-m TCT. SIMULATOR is not used in tunnel control, but can be used for training the operators in using the controller on any PC/AT. BOOT is necessary only when the tunnel control software is to be maintained or modified.

For using the PC/AT microcomputer as a tunnel controller, it should be set up as follows. The operating system MSDOS is loaded into the hard disk C. The tunnel control software CONTROL.EXE and the BASRUN.EXE are then loaded into disk C. *No other software should be mounted in the system.* The AUTOEXEC.BAT is set such that when the microcomputer is powered, the system boots itself on the MSDOS of disk C, and after booting the program, CONTROL.EXE is automatically loaded and executed. The microcomputer exclusively runs the CONTROL.EXE program all the time. This program needs to be stopped only when there is a need for a software update.

CONTROL software:

The 650 line software for tunnel control is written in BASIC for ease of understanding and modifications. The BASIC code of the tunnel controller program is available from the Facility Coordinator. This program is compiled and linked using the BASIC compiler to obtain CONTROL.EXE object code. The software is executed using the combination of CONTROL.EXE and BASRUN.EXE. Appendix B provides the list of the variables used in the tunnel control software. Appendix C provides a program flowchart. Appendix D provides details of the screen display format.

SIMULATOR software:

A tunnel simulation software is available on the diskette SIMULATOR. This simulation can run on any PC/AT with a color monitor. A PC/AT with about 10 MHz clock provides the correct speed and is preferred. The simulation package does not require the DT 2801/5716A or the DT 2815 cards.

1. Copy all the software in SIMULATOR to either the hard disk or to a backup disk using the COPY *.* command. The SIMULATOR disk consists of two files, SIM.EXE and BASRUN.EXE. Type SIM and hit the "Return" key. The monitor displays the typical control display shown in figure 1.

2. The monitor shows starting conditions corresponding to the ambient. The tunnel gas temperature is at 300 K, tunnel metal temperature is at 300 K, tunnel pressure is at 14.70 psia and fan speed at zero. The LN_2 valve, gas discharge valve, and rheostat are at zero. The LN_2 pump is at 11.6 psia and the back pressure valve is fully open. The T-P/Re-M loops are on manual mode.

3. To load the required temperature, letter "T" is used. It provides a prompt with a flashing ",K". The set point 300.0 is then loaded. A Return command transfers temperature set point to the loop and changes the mode to "AUTO". Similarly, pressure loop can be commanded to "AUTOP" with letter "P" command which provides a flashing ",psia" prompt and pressure can be set to 30.00 psia. Letter command "N" provides a flashing ",rpm" prompt and a typical speed command of 2400 rpm slowly starts the tunnel by increasing the fan speed at a rate of 50 rpm/s. When the fan speed crosses 600 rpm, the temperature loop is enabled and the LN_2 pressure set point is switched to 136 psia (default). The tunnel now slowly starts off and stabilizes in automode at 300 K, 30 psia and a fan speed of 2400 rpm. The tunnel test section static pressure is displayed in psia, and varies with fan speed. The tunnel can be taken to any pressure, temperature and fan speed within its operating range by commanding the appropriate numbers. Appendix E gives a complete listing of all input commands.

4. Mach number mode can be addressed by the letter "M" command which transfers the fan speed loop to "AUTO" mode.

5. A tunnel cooldown can be practiced by commanding 100.0 K either at constant speed or at constant Mach number. The tunnel initially cools down the gas at about 20 K/minute and then follows the metal temperature cooling rate. The monitor displays the structural cooling rate GRAD in K/minute. The typical cooling rate at 30 psia and Mach number equal to 0.44 is about 3.4 K/minute. The cooldown rate can be increased by using a higher fan speed or a higher tunnel pressure.

6. Reynolds number mode can be addressed by the letter "R" command which transfers pressure loop to "AUTORE" mode. This requires use of the correct chord data which can be loaded using letter command "C".

7. Letter command "B" allows setting of the LN_2 pressure between 100 and 150 psia.

8. Letter command "D" allows the partial keyboard commands to be cleared.

Exercising this simulator provides a good feel for operating the tunnel controller. The tunnel simulator controls and the 0.3-m TCT controller are duplicates of each other concerning the operator display and commands. Hence, no change in operating techniques is necessary when the actual tunnel is run. However, the dynamics of the tunnel process near tunnel choking conditions, (high Mach number) have not been duplicated, nor has the geometrical disturbances, (adaptive wall movements, angle of attack change, and drag rake movement). While operating the tunnel, these changes have to be kept in mind.

INSTALLATION OF CONTROL SOFTWARE ON A PC/AT

1. Check the microcomputer system configuration to make sure that DT 2801/5716 A and DT 2815 cards are mounted with correct jumper configuration. Make sure that the keyboard is modified.

2. Mount the MSDOS operating system in hard disk C. All other software must be deleted.

3. Copy CONTROL.EXE and BASRUN.EXE to hard disk C.

4. Modify AUTOEXEC.BAT to load automatically CONTROL.EXE for operation.

5. Check the monitor screen to see if the correct display is shown when CONTROL.EXE is loaded.

6. The input signals can be checked by comparing the displayed tunnel variables with the actual signals to make sure that all the displays are correct.

Software modifications:

1. The tunnel software modifications should *be performed by a person who fully understands the BASIC code. This should be performed only with the knowledge and approval of the Facility Safety Head of* 0.3-m TCT. The BASIC code for the tunnel controller is available from the Facility Coordinator. Need for software modification arises only if tunnel geometry changes, the sensors/actuators change, or the microcomputer operating clock speed changes. The software must then be compiled and linked to obtain a new CONTROL.EXE.

2. Since the tunnel controller is always running, to stop the program the BOOT diskette must be put into drive A and the microcomputer power switched off and then switched on. The microcomputer will now boot to disk A. The microcomputer now is running MSDOS.

Change the drive to disk C. The new version should be copied on to drive C: as CONTROL.EXE.

3. To restart the system, the BOOT diskette in A drive must be removed. Again the power must be switched off and then switched on. The system will automatically load the new program.

OPERATION OF TUNNEL CONTROLLER

The microcomputer T-P/Re-M controller is switched on. The monitor needs to be studied first. If the display shows "SENSOR FAILURE", it means that one or more of the seven sensors is out of range. Typically, when the vacuum pump reference for the tunnel pressure sensors is not operating, a sensor failure exists.

The seven sensors used for tunnel control are displayed on the screen. These should be checked for their calibration on the monitor screen. They are:

1. Both the temperature sensors must read the ambient temperature of about 290 K, unless the tunnel is known to be at a colder temperature.

2. The total and static pressure sensors must be calibrated using the Datametrics zero and range controls.

3. The LN_2 pressure sensor reading and calibration must be checked.

4. The PIONEER speed indicator has a CAL button. This signals 3200 rpm command and should be checked on the monitor.

5. The calibration of the screen ΔP must also be checked.

After the sensors are checked, the auto/manual switches for the vent valves #3621, #3622, as well as the LN_2, valve switch for #3535 must be transferred to microcomputer control. The tertiary valve #3623 must be closed.

Once all other ancillary systems and safety devices are checked, the tunnel is ready for operation. The operating procedure is very similar to the details in SIMULATOR section. However, before a cooldown starts, the tunnel needs to be purged of all the moisture. Hence, the tunnel is started at 300 K, 30 psia and 2400 rpm. Once equilibrium conditions are reached, the tunnel is operated for five minutes. At the end of five minutes, the pressure set point is changed to 15 psia so that all the tunnel resident moisture is discharged. The tunnel is brought back to 30 psia. The tunnel is now ready for cooldown to any conditions, under automatic control.

0.3-m TUNNEL T-P/R-M CONTROLLER

	LN PUMP W1	TEMP LOOP W2	Pt/Re LOOP W3	RPM/MACH LOOP W4
SET POINT	W5 ,psia	W6 ,K(Final) W7 ,K(Use)	W8 ,Psia W9 ,Miln/Chrd	W10 ,Mach W11 ,RPM
	FLAG 1	FLAG 2	FLAG 3	FLAG 4
PROCESS	W12 ,psia	W13 ,K-GN2 W14 ,K-WALL	W15 ,Psia W16 ,Miln/Chrd	W17 ,Mach W18 ,RPM
COMMAND	W19 ,%opn	W20 ,% opn	W21 ,% opn V1 W22 ,% opn V2	W23 ,%Rhst W24
INPUTS Delete	B=W25 ,psi	Temp=W26 ,K ALQ%=W27 ,opn	Pres= W28 ,psia Ryno=W29 ,miln AGV%=W30,opn Chrd=W31 ,m	Mach=W32 ,Mach Nrpm=W33,rpm
STATUS		GRAD=W34 ,K/mt SAT=W35 ,K	CHORD=W36 ,m P st=W37 ,psia Del P=W38 ,psi	W39 W40

Figure 1. Display format for the controller monitor.

0.3-m TUNNEL T-P/R-M CONTROLLER

	LN PUMP AUTO	TEMP LOOP AUTO	Pt/Re LOOP AUTOP	RPM/MACH LOOP AUTO
SET POINT	117.6,psia	231.0 ,K(Final) 231.0 ,K(Use)	68.00 ,Psia ,Miln/Chrd	0.765 ,Mach 2400. ,RPM
PROCESS	117.6,psia	231.0 ,K-GN2 231.1 ,K-WALL	68.00 ,Psia 20.06 ,Miln/Chrd	0.765 ,Mach 4412. ,RPM
COMMAND	77.3 ,%opn	41.7 ,% opn	40.0 ,% opn V1 0.0 ,% opn V2	59.,%Rhst
INPUTS Delete	B=	Temp= ALQ%=	Pres= Ryno= AGV%= Chrd=	Mach= Nrpm=
STATUS		GRAD= 0.0 ,K/mt SAT= 98.7 ,K	CHORD=.2286 ,m Pstat=46.16 ,psia Del P= 0.00 ,psi	

Figure 2.- Typical controller monitor display.

REFERENCES

Balakrishna, S. ; and Kilgore, W. Allen : Microcomputer Based Controller for the Langley 0.3-Meter Transonic Cryogenic Tunnel. NASA CR 181808, March 1989.

User Manual for DT 2801 Series, Single Board Analog and Digital I/O System for the IBM Presonal Computer. Data Translation, Inc., Eight Edition. October 1988.

User Manual for DT 2815, D/A Converter Board, IBM PC/XT/AT Compatible. Data Translation, Inc., Second Edition, October 1987.

APPENDIX A

LIST OF INPUT SENSORS FOR THE CONTROLLER

Variable	Channel	Units	Sensitivity	Transducer
PP	E(1)	0-100 psia	0-5 VDC	Barocell
PS	E(2)	0-100 psia	0-5 VDC	Barocell
TT	E(3)	78-342 K	0-5 VDC	Thermocouple
TMWL	E(4)	78-342 K	0-5 VDC	Thermocouple
FRPM	E(5)	0-6400 rpm	0-5 VDC	Tacho
PLQ	E(6)	0-200 psia	0-5 VDC	Transducer
DLP	E(7)	0-5 psid	0-5 VDC	Barocell

OUTPUTS FROM THE CONTROLLER

Channel	Variable	Output	Type	Actuator
DAC(1)	ALQ	4-20 mA	position drive	valve #3531
DAC(2)	ALQ	4-20 mA	position drive	valve #3533
DAC(3)	ALN	4-20 mA	position drive	valve #3535
DAC(4)	AGV1	1-5 VDC	position drive	valve #3621
DAC(5)	AGV2	1-5 VDC	position drive	valve #3622
DAC(6)	SNRPM	0-5 VDC	fan drive command	Rheost servo
DAC(7)	IQ	5 VDC	fan drive reference	Rheost ref.(100%)

APPENDIX B

VARIABLE NAMES IN THE T-P/Re-M CONTROL SOFTWARE OF THE 0.3-M TCT

AA	Keyboard input function. Combines the integer inputs H1, H2, H3, and H5 with proper decimal scaling for use in program calculations.
AEMP	Temporary data register output in DAC routine to check status.
AGV1	Area of GN_2 valve #1. Full open AGV1=1 and closed AGV1=0.
AGV1P	Area of GN_2 valve #1, previous cycle value.
AGV2	Area of GN_2 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.
ALN	Area of LN_2 back pressure control valve. Full open ALN=1 and closed ALN=0.
ALN1	Area of LN_2 back pressure control valve, previous cycle value.
ALQ	Area of LN_2 control valve. Full open ALQ=1 and closed ALQ=0. The command is for all the valves in parallel.
ALQP	Area of LN_2 control valve, previous cycle value.
AUTOM	Logic state Mach number controller: AUTOM=1 automatic Mach number control. AUTOM=0 manual Mach number control. Corresponds to fan speed control.
AUTOP	Logic state pressure controller: AUTOP=1 automatic pressure control. AUTOP=0 manual pressure control.
AUTORE	Logic state Reynolds number controller: AUTORE=1 automatic Reynolds number control. Corresponds to automatic pressure control with the pressure set point generated by the Reynolds number regulation. AUTORE=0 manual Reynolds number control. Corresponds to automatic pressure control.
AUTOT	Temperature Controller: AUTOT=1 automatic temperature control. AUTOT=0 manual temperature control.
BEMP	Temporary status register output in DAC routine to check status.
BSD	Dummy calculation to create a time delay between resetting the DAC and reading its status. Used only during initialization of DAC. BSD=SQR(7)
CEMP	Temporary status register output in DAC subroutine.

CGV	Coefficient for GN_2 discharge valve. CGV=8
CH	Mean aerodynamic chord. Loaded through the keyboard using the "C" command. Default value is CH=0.1800 meters.
CLQV	Flow coefficient for LN_2 injection valve. CLQV=4
D1	Integer used in the LOCATE statements. D1 is added to MU to print properly the first digit of the variable loaded through the keyboard.
D2	Integer used in the LOCATE statements. D2 is added to MU to print properly the second digit of the variable loaded through the keyboard.
D3	Integer used in the LOCATE statements. D3 is added to MU to print properly the third digit of the variable loaded through the keyboard.
D4	Integer used in the LOCATE statements. D4 is added to MU to print properly the fourth digit of the variable loaded through the keyboard.
D5	Integer used in the LOCATE statements. D4 is added to MU to print properly the fifth digit of the variable loaded through the keyboard.
DAC(1)	Control variable ALQ output, (4-20 mA). DAC(1)=ALQ
DAC(2)	Control variable ALQ output, (4-20 mA). DAC(2)=ALQ
DAC(3)	Control variable ALN output, (4-20 mA). DAC(3)=ALN
DAC(4)	Control variable AGV1 output, (1-5 VDC). DAC(4)=AGV1
DAC(5)	Control variable AGV2 output, (1-5 VDC). DAC(5)=AGV2
DAC(6)	Control variable SNRPM output, (0-5 VDC). DAC(6)=SNRPM
DAC(7)	RPM/MACH controller output for Rheostat control. DAC(7)=1 for normal operation. DAC(7)=0 for Rheostat control.
DAC(8)	Spare control variable channel.
DEL	Cycle time step. DEL=0.1 seconds.
DLP	Difference in pressure across the screens of the tunnel settling chamber, (psia). DLP=E(7)*XDLP
DLPC	Maximum safe screen pressure drop allowed. DLPC=0.47*PP*M*M/(MF)^6
DRPM	Fan speed in RPM with a minimum limit of 100 rpm. DRPM=FRPM, DRPM>100
DR1	Command output high integer buffer in DAC routine, (12 bit).
DR2	Command output low integer buffer in DAC routine, (4 bit).
E11	Output from ADC of the tunnel total pressure for monitor display.
E12	Output from ADC of the tunnel static pressure for monitor display.
E(1)	Input millivolts from total pressure sensor.
E(2)	Input millivolts from static pressure transducer.

E(3) Input millivolts from the total temperature thermocouple.

E(4) Input millivolts from the tunnel metal wall temperature thermocouple.

E(5) Input millivolts from the fan speed sensor in RPM.

E(6) Input millivolts from LN_2 pressure transducer.

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

E(8) Spare input channel.

ELP Error in LN_2 pressure control, (atm). ELP=PLQ-SLQ

ELP1 Error in LN_2 pressure control, previous cycle value.

EM Error in Mach number control. EM=SM-M

EN Error in fan speed control, (rpm). EN=NCMDS1-FRPM

EP Error in pressure control, (atm). EP=PP-SPR

EPM1 Error in pressure control, previous cycle value.

EPM2 Error in pressure control, twice previous cycle value.

ET Error in temperature control, (kelvin). ET=TT-ST

ETM1 Error in temperature control, previous cycle value.

ETM2 Error in temperature control, twice previous cycle value.

FB Fan bias, an equivalent of FKW in LN_2 flow. FB=FKW/(121+TT)/LF

FBF Product of FB and FF. FBF=FB*FF*0.8

FF Feed forward logic integer. FF=1 the fan bias is fed forward as LN_2. FF=0 the fan bias is not fed forward as LN_2. The feed forward is off during tunnel warm-ups.

FKW Estimated fan power released to gas, (kilowatts).
FKW=110*PP*(FRPM/1000)^2.26/SQR(TTMP)

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

FL2 Logic flag. FL2=1 when the metal temperature is within 24 K of the tunnel temperature set point. FL2=0 corresponds to a larger temperature difference. FL1*FL2=1 corresponds to the temperature of the tunnel at the 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 less than 0.002. FL4=0 corresponds to larger Mach number control error.

FL5 Logic flag. FL5=1 when the error in the LN_2 pressure control is less than 0.25 atm. FL5=0 corresponds to a larger LN_2 pressure error.

KIM	Mach number control integral gain. KIM=0.0
KIN	Fan speed control integral gain. KIN=0.4
KIP	Pressure control integral gain. KIP=0.05
KIT	Temperature control integral gain. KIT=0.10
KMC	Constant corresponding to tunnel fan speed/test section coupling defined in the control analysis of the Mach number controller. KMC=520*SQR(TT)/PP^-0.035
KMGS	Mach number control gain schedule function. KMGS=KMC*KMM
KMM	Mach number control gain. KMM=0.30
KP	Pressure control gain. KP=0.30
KPGS	Pressure control gain schedule function. KPGS=750*KP/PP/SQR(TT)
KPL	LN_2 pressure control proportional gain. KPL=0.2
KPM	Mach number control proportional gain. KPM=4.50
KPN	Fan speed control proportional gain. KPN=0.6
KPP	Pressure control proportional gain. KPP=1.0
KPT	Temperature control proportional gain. KPT=1.0
KRE	Constant used for evaluating Reynolds number related functions. KRE=63714*CH*M/TT^1.4/(MF)^2.1
KT	Temperature control gain factor. KT=0.04
KTGS	Temperature control gain schedule function. KTGS=DRPM*SQR(PP)*KT/3.0/TT/LF
LCMDS	LN_2 valve area. Loaded through the keyboard using the "L" command.
LDPQ	Difference between LN_2 pressure and total pressure. LDPQ=(PLQ-PP)
LF	LN_2 flow when LN_2 valve is full open. LF=CLQV*0.8676*SQR(LDPQ)
LMT	Limiter for LN_2 flow. Used when the temperature difference between the tunnel metal wall and tunnel gas exceeds MXT.
LO	An output driving the DAC low buffer for final command. Low byte to data register in DAC routine.
LQ	Product of ALQ and 100. LQ=ALQ*100
LU	Screen row numbers used in the LOCATE statements; for display.
M	Tunnel flow Mach number in the test section based on the difference between total and static pressure. M=SQR(5*(PP/PS)^0.28571-5)
MF	Isentropic function of the tunnel flow Mach number. MF=(1+0.2*M*M)
MU	Screen column numbers used in the LOCATE statements; for display.
MXT	Maximum safe temperature difference allowed between tunnel gas and tunnel metal wall.
NCMDS	Fan speed set point. Loaded through the keyboard using the "N" command.

FL6	Logic flag. FL6=1 when the pressure difference across the tunnel screens is unsafe. FL6=0 corresponds to a safe pressure difference.
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. FRPM=E(5)*XFRPM
GCMDS	GN_2 discharge valve area. Loaded through the keyboard using the "G" command.
GF1	Mass flow from the tunnel. GF1=2.725*CGV*PP/SQR(TT)
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.
HI	High byte to DAC buffer of the DAC subroutine.
&H2EC	Port number on the PC/AT microcomputer for ADC.
&H224	Port number on the PC/AT microcomputer for DAC.
&H225	Port number on the PC/AT microcomputer for DAC.
I	Integer cycle counter used to print the 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 DAC variables.
IQ	Logic flag. IQ=1 corresponds to Rheostat control in RPM/MACH control. IQ=0 corresponds to normal operation.
IW	Integer cycle counter, IW=40. Used in integrating the wall temperature gradient. Some control variables are displayed only once in 40 cycles.
J	Integer variable that identifies type of input variable.
JJ	Integer cycle counter for calculation of BSD.
JD	Integer cycle counter for printing certain variables every 4 cycles.
K	Integer cycle counter for a 600 cycle beep.
KDL	LN_2 pressure control derivative gain. KDL=0.0
KDP	Pressure control derivative gain. KDP=0.0
KDT	Temperature control derivative gain. KDT=0.0
KEN	A gradient term limiting the RPM of the fan speed.
KIL	LN_2 pressure control integral gain. KIL=0.20

NCMDS1 Fan speed set point derived from NCMDS or other safety fan speed commands.

PLQ LN_2 pressure, (atm). PLQ=E(6)*XPLQ

PLQUSCS LN_2 pressure, (psia). PLQUSCS=PLQ*14.696

PP Total tunnel pressure, (atm). PP=E(1)*XPP

PPUSCS Total tunnel pressure, (psia). PPUSCS=PP*14.696

PS Tunnel static pressure, (atm). PS=E(2)*XPS

PSUSCS Tunnel static pressure, (psia). PSUSCS=PS*14.696

RE Flow Reynolds number based on aerodynamic chord. RE=KRE*PP

RIL LN_2 control integral error, (atm-sec).

RILM1 LN_2 control integral error, previous cycle value.

RIM Mach number control integral error, (Mach-sec).

RIMM1 Mach number control integral error, previous cycle value.

RIN Fan speed control integral error, (rpm-sec).

RINM1 Fan speed control error integral, previous cycle value.

RIP Pressure control integral error, (atm-sec).

RIPM1 Pressure control integral error, previous cycle value.

RIT Temperature control integral error, (K-sec).

RITM1 Temperature control integral error, previous cycle value.

SAT Saturation temperature based on Jacobsens data, (kelvin). SAT=50+27.34*PS^0.296

SAT1 Saturation temperature for tunnel static pressure, (kelvin). SAT1=SAT*MF

SLQ LN_2 pressure control set point, (atm). SLQ=SLQSC/14.696

SLQSC LN_2 back pressure set point. Loaded through the keyboard using the "B" command. Default value is SLQSC=17 psi for fan "on" and 11 psi for fan "off".

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, (psia). 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 Reynolds number set point. Valid in automatic Reynolds number control mode. SPR1=SRE/KRE

SPRU Tunnel total pressure set point estimated from Reynolds number set point, (psia). SPRU=SPR*14.696

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

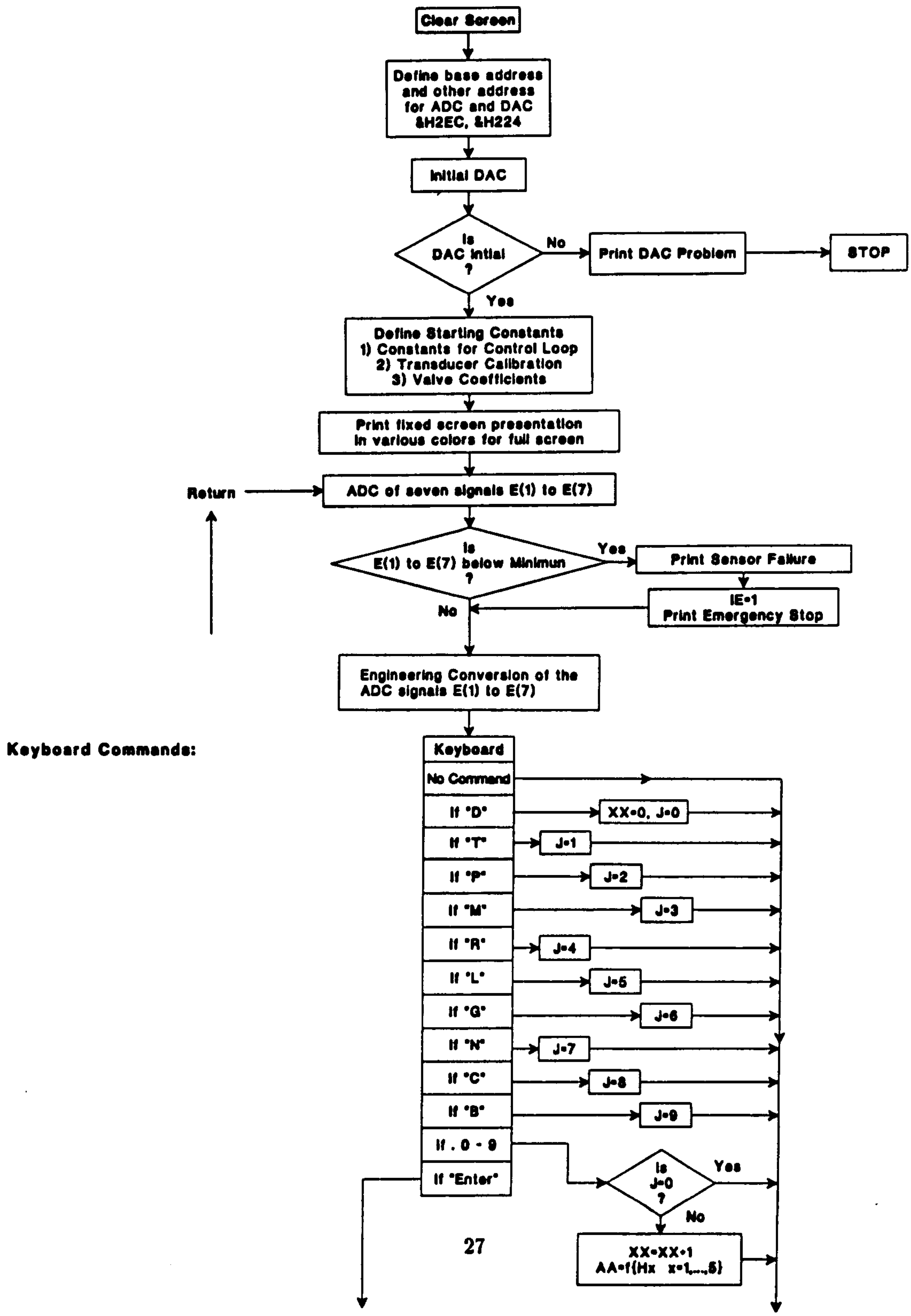
SRPM Fan speed command from control law, (rpm).

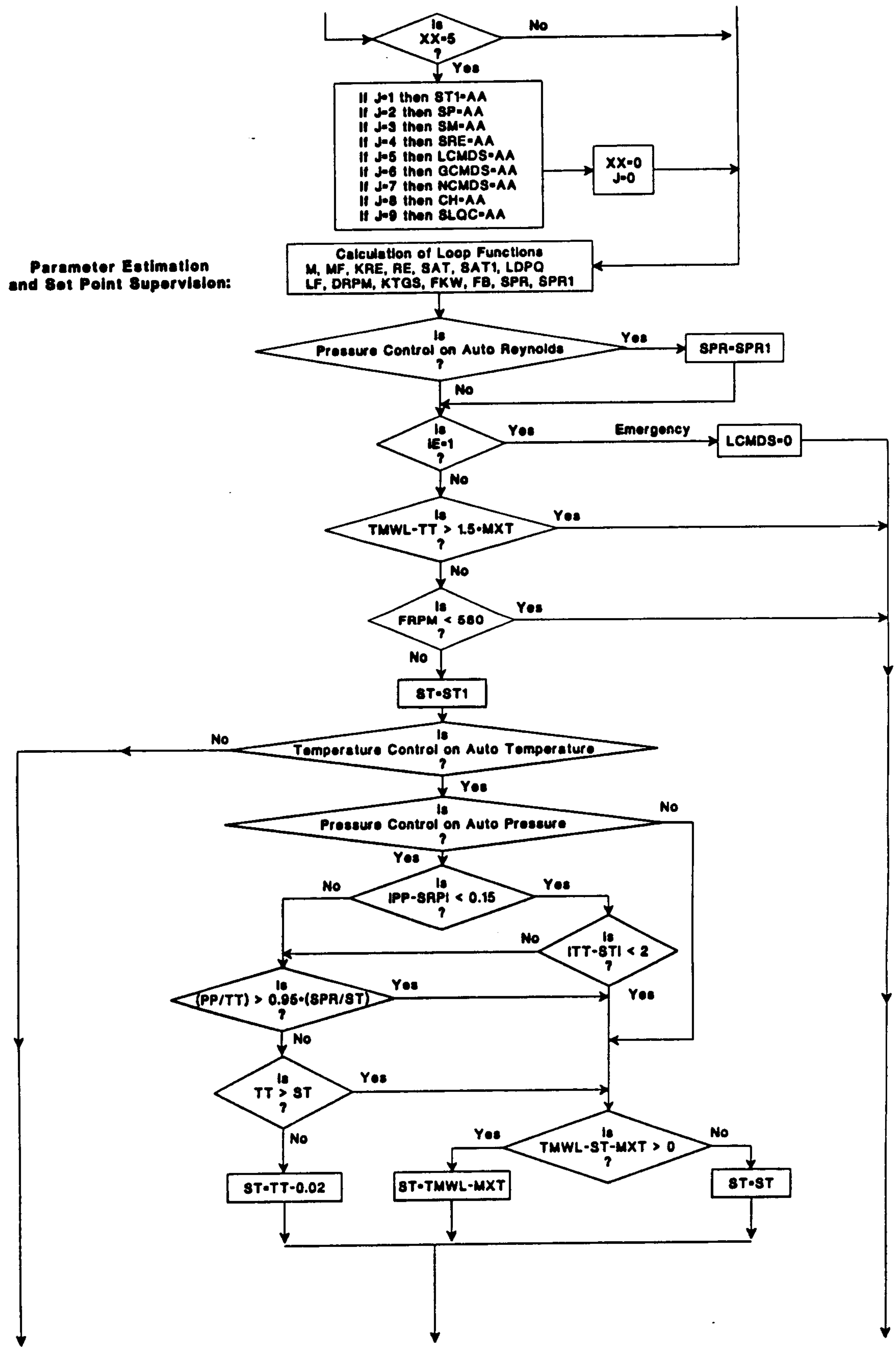
SRPM1	Fan speed command , previous cycle value.
ST	Tunnel total temperature set point. Based on a safe temperature for given tunnel conditions. Also, for the condition when TT and PP are high and the gas mass in the tunnel is inadequate to reach a desired temperature set point.
ST1	Tunnel total temperature set point. Loaded through the keyboard using the "T" command.
STP	Total temperature set point ramp generator. Restricts the rate of temperature change to 0.04 K/cycle or 24 K/minute.
TMWL	Tunnel metal wall temperature, (kelvin).
TMWL1	Tunnel metal wall temperature, previous cycle value.
TT	Total temperature of tunnel gas, (kelvin).
TTMP	Total temperature of tunnel gas with a minimum limit of 80 K. TTMP=TT
WLG	Rate of change for the tunnel metal wall temperature. Wall temperature gradient.
XDPL	Screen pressure drop transducer sensitivity. XDPL=1.000
XFRPM	Fan speed sensor sensitivity. XFRPM=1280
XPLQ	LN_2 pressure sensor sensitivity. XPLQ=2.6539
XPP	Stagnation pressure transducer sensitivity. XPP=1.366
XPS	Static pressure transducer sensitivity. XPS=1.366
XRPM	Fan constant. XRPM=KMC*SM*(1-0.3*SM)
XX	Integer counter between 0 to 5. Represents the number of keyed in characters while inputing set points into the controller.
Z	Defined as an integer variable.
ZDCHNL	Analog to digital conversion channel number.
ZDGAIN	ADC gain switch at software level.
ZOL#	ADC output normalized to 5 volts.
ZOLT#	ADC output as a 16 bit binary number.
ZOW	Low byte of ADC output.
ZIGH	High byte of ADC output.
ZTATUS	Status of the ADC register.

APPENDIX C

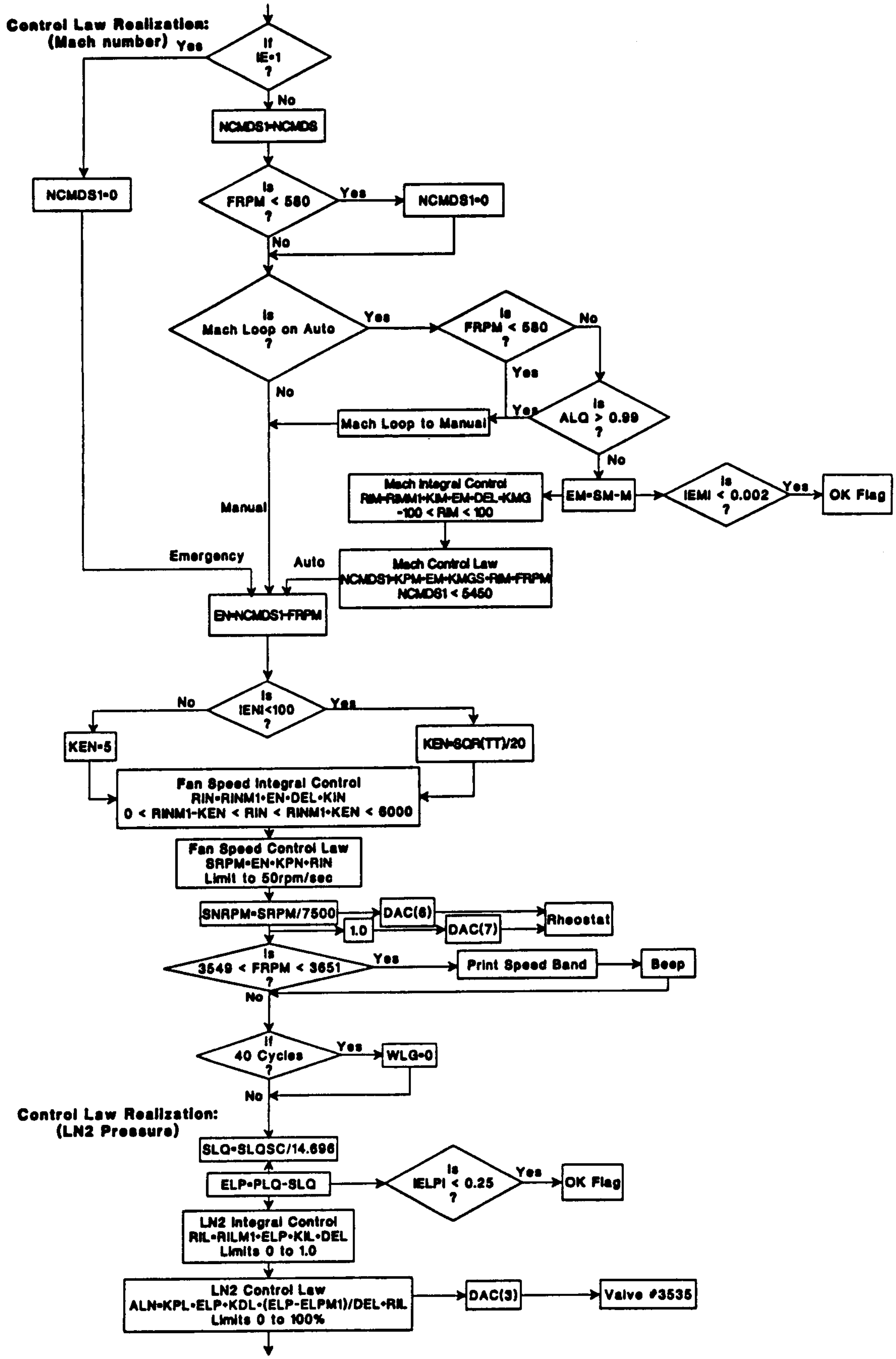
CONTROL PROGRAM FLOWCHART

(Program available from Facility Coordinator)

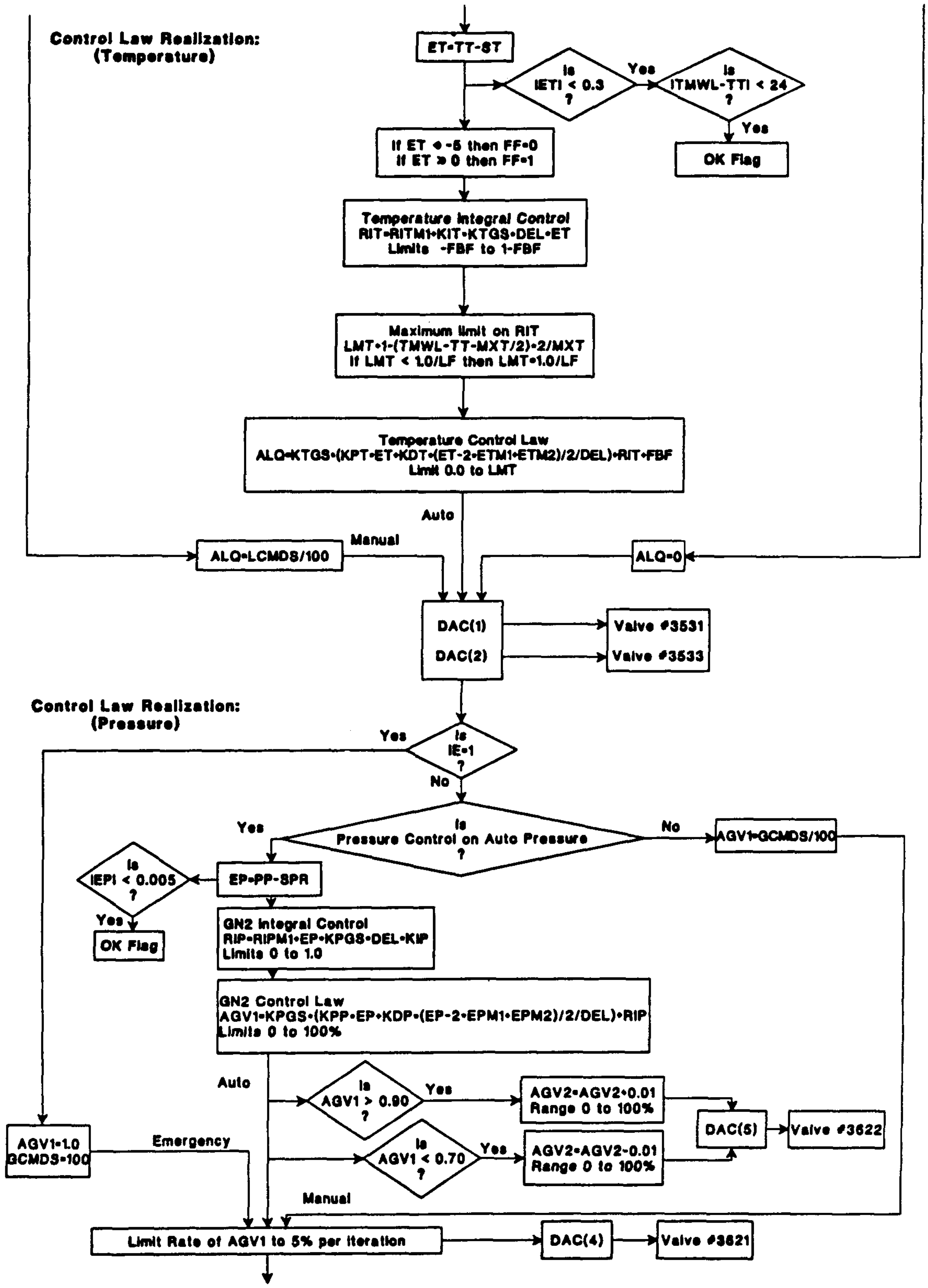


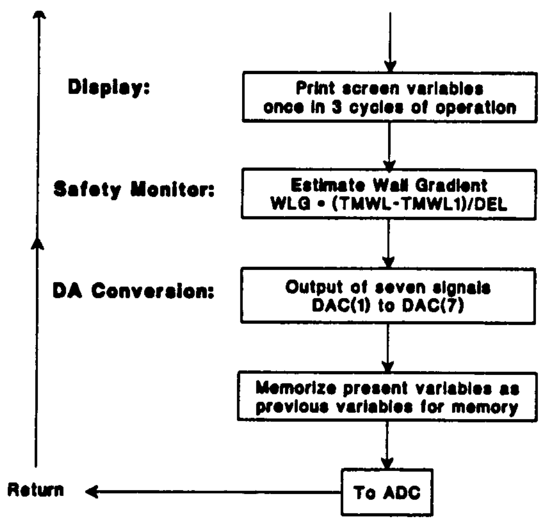


Is XX=5 ?
No
Yes
If J=1 then ST1=AA
If J=2 then SP=AA
If J=3 then SM=AA
If J=4 then SRE=AA
If J=5 then LCMDS=AA
If J=6 then GCMDS=AA
If J=7 then NCMDS=AA
If J=8 then CH=AA
If J=9 then SLQC=AA
XX=0
J=0
Parameter Estimation and Set Point Supervision:
Calculation of Loop Functions
M, MF, KRE, RE, SAT, SAT1, LDPQ
LF, DRPM, KTGS, FKW, FB, SPR, SPR1
Is Pressure Control on Auto Reynolds ?
Yes
SPR=SPR1
No
Is IE=1 ?
Yes
Emergency
LCMDS=0
No
Is TMWL-TT > 1.5*MXT ?
Yes
No
Is FRPM < 580 ?
Yes
No
ST=ST1
Is Temperature Control on Auto Temperature ?
No
Yes
Is Pressure Control on Auto Pressure ?
No
Yes
Is IPP-SRPI < 0.15 ?
No
Yes
Is ITT-STI < 2 ?
No
Yes
Is (PP/TT) > 0.95*(SPR/ST) ?
Yes
No
Is TT > ST ?
Yes
No
Is TMWL-ST-MXT > 0 ?
Yes
No
ST=TT-0.02
ST=TMWL-MXT
ST=ST



Control Law Realization:
(Mach number)
If IE=1 ?
Yes
No
NCMDS1=NCMDS
NCMDS1=0
Is FRPM < 580 ?
Yes
NCMDS1=0
No
Is Mach Loop on Auto ?
Yes
Is FRPM < 580 ?
No
Yes
Is ALQ > 0.99 ?
Yes
No
Mach Loop to Manual
Mach Integral Control
RIM=RIMM1+KIM•EM•DEL•KMG
-100 < RIM < 100
EM=SM-M
Is IEMI < 0.002 ?
Yes
OK Flag
Manual
Emergency
Auto
Mach Control Law
NCMDS1=KPM•EM•KMGS+RIM+FRPM
NCMDS1 < 5450
EN=NCMDS1-FRPM
Is IENI<100 ?
No
Yes
KEN=5
KEN=SQR(TT)/20
Fan Speed Integral Control
RIN=RINM1+EN•DEL•KIN
0 < RINM1-KEN < RIN < RINM1+KEN < 6000
Fan Speed Control Law
SRPM=EN•KPN+RIN
Limit to 50rpm/sec
SNRPM=SRPM/7500
DAC(6)
Rheostat
1.0
DAC(7)
Is 3549 < FRPM < 3651 ?
Yes
Print Speed Band
Beep
No
If 40 Cycles ?
Yes
WLG=0
No
Control Law Realization:
(LN2 Pressure)
SLQ=SLQSC/14.696
ELP=PLQ-SLQ
Is IELPI < 0.25 ?
Yes
OK Flag
LN2 Integral Control
RIL=RILM1+ELP•KIL•DEL
Limits 0 to 1.0
LN2 Control Law
ALN=KPL•ELP+KDL•(ELP-ELPM1)/DEL+RIL
Limits 0 to 100%
DAC(3)
Valve #3535


Control Law Realization:
(Temperature)
ET=TT-ST
Is
|ET| < 0.3
?
Yes
Is
|TMWL-TT| < 24
?
Yes
OK Flag
If ET <-5 then FF=0
If ET > 0 then FF=1
Temperature Integral Control
RIT=RITM1+KIT*KTGS*DEL*ET
Limits -FBF to 1-FBF
Maximum limit on RIT
LMT=1-(TMWL-TT-MXT/2)*2/MXT
If LMT < 1.0/LF then LMT=1.0/LF
Temperature Control Law
ALQ=KTGS*(KPT*ET+KDT*(ET-2*ETM1+ETM2)/2/DEL)+RIT+FBF
Limit 0.0 to LMT
Auto
Manual
ALQ=LCMDS/100
ALQ=0
DAC(1)
DAC(2)
Valve #3531
Valve #3533
Control Law Realization:
(Pressure)
Yes
Is
IE=1
?
No
Yes
Is
Pressure Control on Auto Pressure
?
No
AGV1=GCMDS/100
Is
|EP| < 0.005
?
EP=PP-SPR
Yes
OK Flag
GN2 Integral Control
RIP=RIPM1+EP*KPGS*DEL*KIP
Limits 0 to 1.0
GN2 Control Law
AGV1=KPGS*(KPP*EP+KDP*(EP-2*EPM1+EPM2)/2/DEL)+RIP
Limits 0 to 100%
Auto
Is
AGV1 > 0.90
?
Yes
AGV2=AGV2+0.01
Range 0 to 100%
DAC(5)
Valve #3622
AGV1=1.0
GCMDS=100
Emergency
Is
AGV1 < 0.70
?
Yes
AGV2=AGV2-0.01
Range 0 to 100%
Manual
Limit Rate of AGV1 to 5% per Iteration
DAC(4)
Valve #3621



Display:
Print screen variables once in 3 cycles of operation
Safety Monitor:
Estimate Wall Gradient WLG = (TMWL-TMWL1)/DEL
DA Conversion:
Output of seven signals DAC(1) to DAC(7)
Memorize present variables as previous variables for memory
To ADC
Return

APPENDIX D

DETAILS OF THE MONITOR DISPLAY FOR TUNNEL CONTROL

(refer to figures 1 and 2)

W1 Displays the status of LN_2 control as "AUTO". It cannot be changed. The LN_2 control is always on automatic mode.

W2 Displays the status of temperature control loop. Three modes are possible:
"AUTO" in yellow for temperature control operation using temperature set point.
"MANUAL" in yellow for LN_2 injection valve area control.
"MANUAL" in red for emergency command.

W3 Displays status of pressure control loop. Four modes are possible:
"AUTOP" in yellow for pressure control operation using pressure set point.
"AUTORE" in yellow for pressure control with Reynolds number generated pressure set point.
"MANUAL" in yellow for GN_2 discharge valve area control.
"MANUAL" in red for emergency command of 100% for GN_2 discharge valve position.

W4 Displays status of fan speed control. Three modes are possible:
"AUTO" in yellow for fan speed control operation using Mach number set point.
"MANUAL" in yellow for fan speed control using fan speed set point.
"MANUAL" in red for emergency command of zero fan speed.

W5 Displays the LN_2 pressure control set point. Set to 11 psia for fan speed below 580 rpm. Switches to 132 psia for fan speed $\geq$ 580 rpm. Is loaded from the keyboard by letter command "B". Updated only on a new set point command.

W6 Displays the tunnel temperature control set point. Is loaded from the keyboard by letter command "T". Updated only on a new command.

W7 Displays the tunnel temperature set point actually used as estimated by control law based on gas-metal temperature difference, set point magnitude and direction, tunnel trajectory direction. Updated every 0.3 seconds.

W8 Display of the tunnel pressure set point as desired by operator in "AUTOP" mode. Is loaded from the keyboard by letter command "P". Updated on a new set point command. Also displays pressure set point as estimated by Reynolds number when in "AUTORE" mode. Updated every 0.3 seconds.

W9 Displays Reynolds number set point desired by operator. Is loaded from the keyboard by letter command "R". Updated on a new set point command.

W10 Displays Mach number set point as desired by operator. Is loaded from the keyboard by letter command "M". Updated on a new set point command.

W11 Displays fan speed set point as desired by the operator. Is loaded from the keyboard by letter command "N". Updated on a new set point command.

W12 Displays the true LN_2 supply pressure measured by the transducer. Updated every 0.3 seconds.

W13 Displays the true gas temperature in the tunnel settling chamber. Updated every 0.3 seconds.

W14 Displays the true metal temperature on the tunnel aluminum shell at the third corner. Updated every 0.3 seconds.

W15 Displays the tunnel total pressure measured in the tunnel settling chamber. Updated every 0.3 seconds.

W16 Displays the tunnel flow Reynolds number based on the chord. If chord data is not given Reynolds number is based on default value of a chord of 0.1800 m. Updated every 0.3 seconds.

W17 Displays the true flow Mach number in the test section using the difference between measured total and static pressures. For no flow conditions, the estimate is clipped to be > 0.001 to avoid arithmetic problems in program. Updated every 0.3 seconds.

W18 Displays the true measured fan speed in RPM from the sensor. Updated every 0.3 seconds.

W19 Displays the command to LN_2 back pressure valve generated by the LN_2 pressure control law. Display is in percent for 4-20 mA current drive. Updated every 0.3 seconds.

W20 Displays the command to the LN_2 injection valves in percent. This corresponds to 4-20 mA signal going to the coils. In "AUTO" mode the command is from the temperature control law. In "MANUAL" the command is from position command, limited by metal-gas temperature difference.

W21 Displays the command to gas discharge electrohydraulically driven valve 1.
In "AUTO" mode the drive is derived from the pressure control law.
In "MANUAL" mode the driver is derived from the area control command.
Display of 0-100% corresponds to 1-5 VDC set point commands to electrohydraulic valve 1.

W22 Display corresponds to gas discharge electrohydraulic valve 2 in "AUTO" mode.
Display of 0-100% corresponds to 1-5 VDC set point command to electrohydraulic valve 2.

W23 Displays the fan speed rheostat position command in percent. This is the set point to the position servo driving the field coil of the variable frequency generator. 0-100% corresponds to 0-5 VDC to position servo set point.

W24 Display area normally blank. When the fan speed is between 3550-3650 rpm, the display shows "SPEED BAND" to alert the operator about the singularity of the speed control system.

W25 Letter "B" enables this display with a flashing ",psia". Numeric inputs from the operator in format ###.# forms the LN_2 pressure set point and is displayed as loaded. Return command transfers it to the LN_2 control loop and clears the display. "D" command clears the display without transferring it to control.

W26 Letter "T" enables this display with a flashing ",K". Numeric inputs from the operator in format ###.#, forms the temperature set point and is displayed as loaded. Return command transfers the set point to temperature control loop, transfers the control to "AUTO" and clears the display. "D" command clears the display without transferring it to control.

W27 Letter "L" enables this display with a flashing ",% opn". Numeric inputs from the operator in the format ##.##, forms the LN_2 valve area set point and is displayed as loaded. Return command transfers the set point to the controller, transfers control to "MANUAL" and clears the display. "D" command clears the display without transferring it to control.

W28 Letter "P" enables this display with a flashing ",psia". Numeric inputs from the operator in the format ##.##, forms the pressure set point and is displayed as loaded. Return command transfers the tunnel pressure set point to the controller, transfers the control to AUTOP and clears the display. "D" command clears the display without transferring it to control.

W29 Letter "R" enables this display with a flashing ",miln/chrd". Numeric inputs from the operator in the format ##.##, forms the Reynolds number set point and is displayed as loaded. Return command transfers the Reynolds number set point to the controller, takes the control to "AUTORE" and clears the display. "D" command clears the display without transferring it to control.

W30 Letter "G" enables this display with a flashing "% opn". Numeric inputs from the operator in the format ##.##, forms the discharge valve 1 position set point and is displayed as loaded. Return command transfers the set point to controller, transfers control to "MANUAL" and clears the display. "D" command clears the display without transferring it to control.

W31 Letter "C" enables this display with a flashing ",m". Numeric inputs from the operator in the format .####, forms the model aerodynamic chord for Reynolds number estimation, and is displayed as loaded. Return transfers this chord to Reynolds number estimation and clears the display. "D" command clears the display without transferring it to control.

W32 Letter "M" enables this display with a flashing ",Mach". Numeric inputs from the operator in the format #.###, forms the Mach number set point and is displayed as loaded. Return command transfers the Mach number set point to the controller, transfers control to "AUTO" and clears the display. "D" command clears the display without transferring it to control.

W33 Letter "N" enables this display with a flashing ",rpm". Numeric inputs from the operator in the format ####., forms the fan speed set point and is displayed as loaded. Return command transfers the fan speed set point to the controller, transfers control to "MANUAL" and clears the display. "D" command clears the display without transferring it to control.

W34 Metal temperature time gradient as a cooling or a warm up rate in K/min is displayed in this block. This display is updated every 4 seconds since this time is required to average the gradient.

W35 This displays the saturation temperature of tunnel test section gas, based on the tunnel static pressure. Updated every 0.3 seconds.

W36 This displays the mean aerodynamic chord used for Reynolds number estimation. The chord of the model can be loaded though "C" command. Default chord is displayed in white whereas the chosen chord length is shown in yellow. Updated on a new command.

W37 This displays measured tunnel test section static pressure. Updated every 0.3 seconds.

W38 The measured pressure drop across the screen in the settling chamber is shown in this display area. The actual pressure drop is compared with an ideal pressure drop. If the actual pressure indicates on set of icing, this display starts flashing.

W39 This display is normally blank. When the sensors go out of meaningful signal range, this display shows "SENSOR FAILURE" in red. This clears by itself once the signals are normal.

W40 This display is normally blank. When the tunnel is on an emergency shutdown, this displays "EMERGENCY SHUTDOWN". This can be cleared by "D" command or new set point commands, when the emergency condition no longer exists.

Flag 1 On when the absolute value of LN_2 pressure loop error is less than 0.25 atm. Updated every 0.3 seconds.

Flag 2 On when the absolute value of the tunnel temperature loop error is less than 0.2 K. Updated every 0.3 seconds.

$\boxed{\text{Flag 3}}$ On when the absolute value of the pressure loop error is less than 0.006 atm. Updated every 0.3 seconds.

$\boxed{\text{Flag 4}}$ On when the absolute value of Mach number loop error is less than 0.002. Updated every 0.3 seconds.

APPENDIX E

INPUT KEYBOARD COMMANDS

B,b	Input LN_2 back pressure set point. LN_2 back pressure set point format is ###.#, range is LN_2 pressure to 150 psia.
C,c	Input mean aerodynamic chord. Chord format is .####, range is 0.010 to 0.400 meters.
D,d	Delete the previous input keys memorized on screen and not yet executed.
G,g	Input GN_2 discharge valve area. Takes the pressure controller and Reynolds number controller to manual control mode. GN_2 valve area format is ##.##, range is 99.99%=full open to 0%=closed.
L,l	Input LN_2 valve area. Takes the temperature controller to manual mode. LN_2 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 pressure set point. Takes the controller to automatic pressure control mode and manual Reynolds number control mode. Pressure set point format is ##.##, range is 14.7 to 88 psia.
R,r	Input Reynolds number set point. Takes the pressure control 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/chord.
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.

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Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-181868		

4. Title and Subtitle	5. Report Date
The NASA Langley Research Center 0.3-m Transonic Cryogenic Tunnel T-P/Re-M Controller Manual	July 1989
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
S. Balakrishna and W. Allen Kilgore	
	10. Work Unit No.
	505-61-01-09
9. Performing Organization Name and Address	11. Contract or Grant No.
Vigyan, Inc. 30 Research Drive Hampton, VA 23666-1325	NAS1-17919
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Contractor Report
National Aeronautics and Space Administration Langley Research Center Hampton, VA 23665-5225	14. Sponsoring Agency Code

15. Supplementary Notes

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16. Abstract

A new microcomputer based controller for the 0.3-m Transonic Cryogenic Tunnel (TCT) has been commissioned in 1988 and has reliably operated for more than a year. The tunnel stagnation pressure, gas stagnation temperature, tunnel wall structural temperature and flow Mach number are precisely controlled by the new controller in a stable manner. This report describes the tunnel control hardware, software, and the flow chart to assist in calibration of the sensors, actuators, and the controller real time functions. The software installation details are also presented. The report serves as the maintenance and trouble shooting manual for the 0.3-m TCT controller.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Cryogenic Wind Tunnel Microcomputer Controller	Unclassified - Unlimited Subject Category: 09

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	40	A03

NASA FORM 1626 OCT 86