IN-09
4775
16P

NASA Technical Memorandum 109105

Application of Fuzzy Logic to the Control of Wind Tunnel Settling Chamber Temperature

D. A. Gwaltney and G. L. Humphreys
Langley Research Center, Hampton, Virginia

(NASA-TM-109105) APPLICATION OF FUZZY LOGIC TO THE CONTROL OF WIND TUNNEL SETTLING CHAMBER TEMPERATURE (NASA. Langley Research Center) 16 p

N94-30200

Unclas

G3/09 0004775

March 1994

National Aeronautics and
Space Administration
Langley Research Center
Hampton, Virginia 23681-0001

ABSTRACT

The application of Fuzzy Logic Controllers (FLC's) to the control of nonlinear processes, typically controlled by a human operator, is a topic of much study. Recent application of a microprocessor-based FLC to the control of temperature processes in several wind tunnels has proven to be very successful. The control of temperature processes in the wind tunnels requires the ability to monitor temperature feedback from several points and to accommodate varying operating conditions in the wind tunnels. The FLC has an intuitive and easily configurable structure which incorporates the flexibility required to have such an ability. The design and implementation of the FLC is presented along with process data from the wind tunnels under automatic control.

INTRODUCTION

Recently, the application of Fuzzy Logic Controllers (FLC's) to various processes has proved to be highly successful. In the 1970's, King and Mamdani studied the application of FLC's to the control of nonlinear industrial processes that typically can only be controlled successfully by a human operator[1]. This idea has become a common solution in recent years, with applications ranging from automation of industrial processes to control of electronic devices in consumer products. The design and application of a FLC for the control of settling chamber temperature in several wind tunnels at NASA's Langley Research Center (LaRC) in Hampton, VA, is described. The reader is assumed to have a basic knowledge of Fuzzy Logic. Those unfamiliar with the concepts of Fuzzy Logic are referred to [2]. A comprehensive overview of FLC concepts is given by Lee[3].

At NASA LaRC, the High Pressure Air Distribution System Control Room provides control of air flow to six research tunnels in the Hypersonic Blowdown Tunnels Building. The air is supplied by a high pressure bottlefield through a series of modulating valves and an electric heater to the tunnel in operation. Ultimately, the control objective is to provide the settling chamber temperature and pressure desired by the researcher performing tests in the tunnel. Control of pressure and flow processes with modulating valves is achieved using microprocessor-based Proportional-Integral-Derivative (PID) control loops, with pressure or flow feedback. The application of PID control loops to the temperature processes in the system results in unacceptable control with respect to operation within system temperature constraints and regulation of the controlled process at the desired temperature. A PID control loop is unable to acceptably handle the long delay time in temperature response associated with air flow through long lengths of metal piping which absorb thermal energy. The recent application of a FLC provides appropriate control of the heaters to obtain the desired settling chamber temperature.

SYSTEM DESCRIPTION

The High Pressure Air Distribution System is divided into two sections, the Mach 6 System and the Mach 8 System. Pressurized air is provided by a storage bottlefield. Each system has an electric heater through which air flows before reaching the tunnel in operation. The Mach 8 System also includes a cold air by-pass around the heater. This configuration combines heated and cold air flows through a mixing-tee before reaching the tunnel in operation. In both systems, tunnels not in operation are isolated from the air supply piping by motorized valves or solenoid controlled valves. Only one tunnel is permitted to be in operation at a time. Air flow to the tunnels is modulated through pneumatically actuated valves. These valves are operated manually or are controlled automatically. During manual operation, the valve stem positions are commanded directly. During automatic operation, the valve stem positions are commanded by microprocessor-based PID loops, using flow or pressure feedback. In all cases, the air flows to a settling chamber and then through a nozzle to reach the tunnel test section. Air may exit the tunnel test section through a diffuser to a vacuum chamber or to the atmosphere. Schematic diagrams of the air supply sections are given in Figures 1 and 2. Presently, the Mach 6 System supplies air to two tunnels and the Mach 8 System supplies air to four tunnels.

The heaters for the High Pressure Air Distribution System are electric heaters requiring three-phase AC voltage input which is controlled by a Silicon Controlled Rectifier (SCR). The heater command is a 4-20 ma signal to the SCR voltage controller. The air flowing into the heaters passes through a bundle of electrical resistance heated tubes to maximize air contact with heated metal. The Mach 6 System heater is rated for 11.5 MW maximum power and 60 lbs/sec maximum air flow, while the Mach 8 System heater is rated for 12.75 MW maximum power and 40 lbs/sec maximum air flow.

Automatic control of tunnel processes is provided by two Intel 486/125 microprocessor boards, one dedicated to each system. The microprocessors acquire analog process data and update analog control commands at a rate of 10 Hz. A Programmable Logic Controller (PLC) monitors tunnel states and provides emergency shutdown of the system in operation in the event of process constraint violation or control system failure.

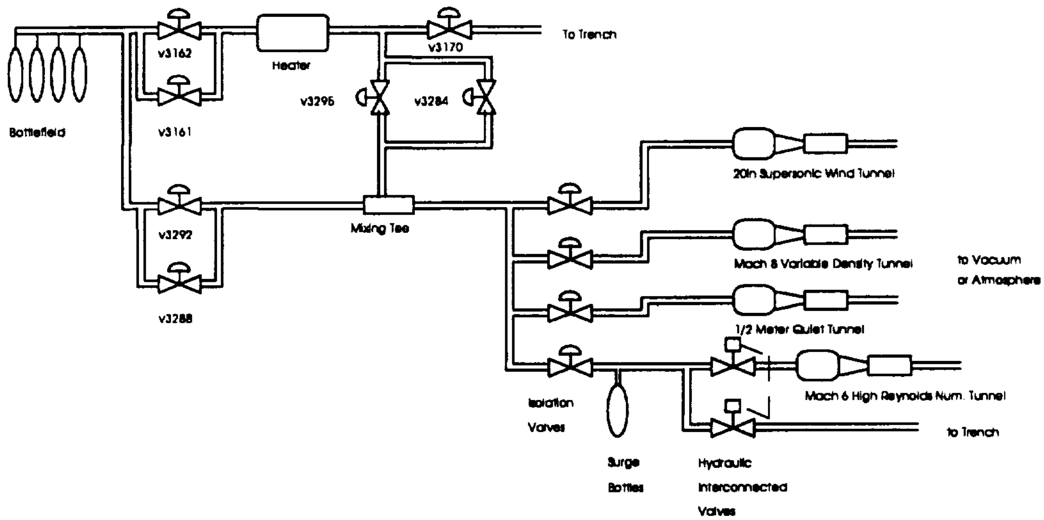

Figure 1. Mach 8 System Schematic

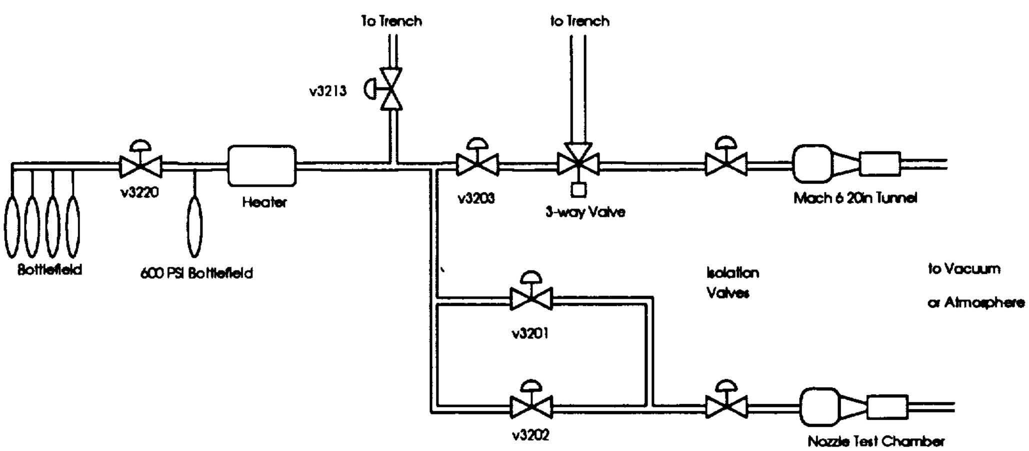

Figure 2. Mach 6 System Schematic

OPERATIONAL PROCEDURE

Typical operation of a tunnel includes a pre-heat phase at startup. During the pre-heat phase, heated air flow is directed through piping to a trench with exhaust to the atmosphere or through the tunnel to be operated. This serves to warm up the heaters and to reduce the heat transfer from the air to the metal piping during the operation of the tunnels, thus reducing the control effort needed to maintain a desired tunnel settling chamber pressure. When the pre-heat phase is complete, air flow is directed to the tunnel. Depending upon the tunnel being operated, the air flow must be completely stopped at the end of the pre-heat phase, and then resumed for the research operation of the tunnel. In some tunnels, the air flow can be redirected through the use of valves.

Several operating constraints concerning temperature exist for both the Mach 6 System and the Mach 8 System. In the Mach 6 System, the heater tube bundle temperature cannot exceed 800 ^{o}F, and the trench air temperature should not exceed 600 ^{o}F. In the Mach 8 System, the heater outlet air temperature cannot exceed 900 ^{o}F, and the trench air temperature should not exceed 550 ^{o}F. Additionally, the Mach 8 System mixing-tee has a constraint requiring the differential between the air temperature and the metal temperature not exceed 200 ^{o}F. Violation of these constraints causes process alarms to be tripped. Excessive violation of these constraints causes an emergency stop , and may cause damage to the air supply piping.

FUZZY LOGIC CONSTRUCTS

The FLC uses fuzzy logic constructs implemented in a set of library routines. This library includes routines that create and use fuzzy sets, fuzzy variables and fuzzy tables. A fuzzy set describes some mode or condition of a process such as "temperature error is positive large." The fuzzy construct implementation allows a fuzzy set to have a trapezoidal, triangular or amodal (plateau) shaped membership function, as illustrated in Figure 3. A fuzzy variable is a group of fuzzy sets associated with a common variable such as "the controlled temperature process." The fuzzy logical-AND of two input fuzzy variables with a resulting output fuzzy variable is described in a fuzzy lookup table. An example of such a table is presented in Table I. Table I represents the fuzzy logical-AND of the controlled temperature process error and the temperature process rate with a command output scheme that seeks to reduce the process error to zero. For instance, one of the table entries is the equivalent of "if Temperature_Error is Positive-Large and Temperature_Rate is Zero then make Delta_Heater_Command Positive-Large." Each combination of the Temperature_Error and Temperature_Rate fuzzy sets can invoke one of the Delta_Heater_Command fuzzy sets. The output fuzzy variable is then defuzzified to obtain a crisp output value.

The approach to implementation attempts to balance programmer ease of use, target code simplicity and run-time efficiency. The routines are written in C and have been run through various compilers to improve library source code portability. The fuzzy constructs are invoked using function calls to the library. To reduce execution time, the fuzzification of a crisp variable into a fuzzy set occurs only once per iteration and only if the given fuzzy set is invoked in a rule. Using a fuzzy table to implement the fuzzy logical-AND of two fuzzy variables reduces the combinations of the corresponding fuzzy sets that must be computed to the non-zero cases. An increase in table size causes a minimal (arithmetic) penalty in execution time. Correlation-product inference is used to simplify computation, and an approximate centroid method, which ignores fuzzy set overlap, is used for defuzzification[4].

Table I. Heater command lookup Table

		Temperature Error						
		NegL	NegM	NegS	Zero	PosS	PosM	PosL
Temperature Rate	NegL	Zero	PosL	PosM	PosM	PosL	PosL	PosL
	NegS	NegM	Zero	PosS	PosS	PosM	PosL	PosL
	Zero	NegL	NegS	Zero	Zero	Zero	PosS	PosL
	PosS	NegL	NegL	NegM	NegS	NegS	Zero	PosM
	PosL	NegL	NegL	NegL	NegM	NegM	NegL	Zero

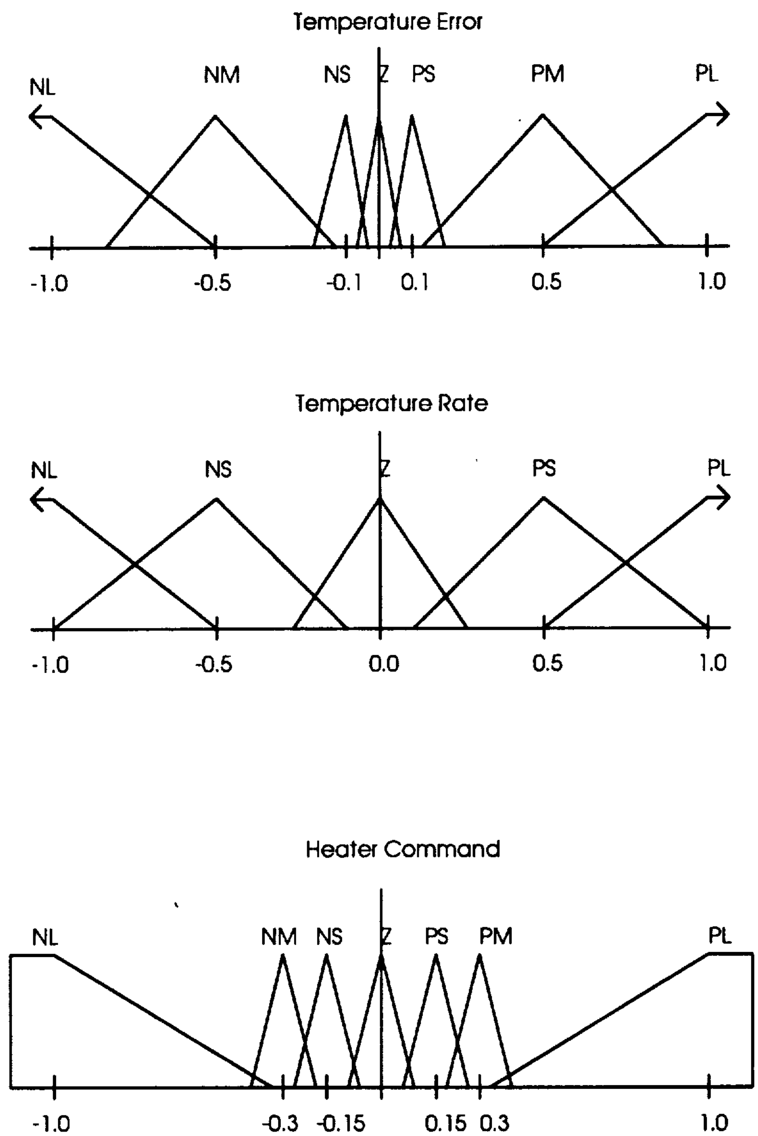

Figure 3. Process and Command Fuzzy Sets

FLC ALGORITHM

The FLC control algorithm consists of an initialization module and an iterative control module. The initialization module configures the fuzzy sets and the lookup tables. For both the Mach 8 System and the Mach 6 System, a main control table using process error and process rate to provide a heater control command is configured as shown in Table I. The fuzzy sets for process error and process rate are dimensionless and are defined so that a large error, or rate, value is considered to be 1.0 to infinity, and the fuzzy sets representing smaller values are defined over the interval (-1.0,1.0). The heater control command fuzzy sets are dimensionless and are defined such that the maximum magnitude of the change in command is 1.0. The sets are illustrated in Figure 3.

In addition, constraint fuzzy sets and lookup tables are configured for each instance of process temperature constraint that must be considered. In addition to the temperature constraints imposed by the physical characteristics of the air distribution systems (as described in the section titled OPERATIONAL PROCEDURES), another constraint is placed on the control action of the FLC. In the Mach 6 System, the difference in the heater tube temperature and the downstream temperature setpoint is not allowed to exceed a specified limit when the process error is negative. This keeps the algorithm from effectively shutting off the heater in an attempt to reach a cooler downstream temperature. Rapid and frequent transition from a heater power command of 0% to a higher percentage command causes undesirable stress on the heaters. This constraint is applied to the heater outlet temperature in the Mach 8 System. The FLC structure provides an intuitive and easily configurable method of considering process constraints. The rule-based framework allows consideration of temperature process constraint rules at several measurement points in the flow path simultaneously with rules for control of the settling chamber or trench temperature, a feat impossible to implement properly when using a simple computation-based control algorithm, such as a PID. Inclusion of such constraints is extremely cumbersome to implement if the "if-then-else" functions of a programming language, such as C or FORTRAN, are used in conjunction with a control algorithm such as a PID.

In the control module, process error is defined as the process setpoint minus the process feedback. The process rate is the difference between the present process value and the previous process value divided by the data sampling period. Both the process feedback and the process rate are filtered using a first order filter with the pole at 0.5 Hz. Process error and rate are multiplied by a scale factor before being fuzzified, and the control command is multiplied by a scale factor after being defuzzified. The heater control command calculated by the defuzzifying function is multiplied by the command scale factor and added to the previous control command. Thus, the command scale factor is a rate limit on the integrating function which calculates the heater control command. The process error, process rate, and command scaling factors are configured to provide different "tunings" for the operation of different tunnels. If necessary, these scaling factors can be scheduled using the settling chamber pressure feedback to accommodate changing process conditions in a specific tunnel. This feature provides the flexibility needed to apply a common routine to the control of different tunnels within each system.

The control module uses all rule lookup tables that are applicable during operation of a tunnel. However, if a temperature constraint is close to being violated at a monitored temperature process, the controller switches to the exclusive use of the constraint lookup table associated with the temperature process in question. This switch is based on the degree of fuzzy membership of the temperature process being monitored in the fuzzy set representing the constraint. For example, when the heater outlet temperature in the Mach 8 system is a member of the fuzzy set denoting "HI" temperature to the degree 0.5 or higher, the switch for the heater outlet constraint lookup table is set. When the temperature process is no longer a member of the constraint fuzzy set to the degree specified, the controller once again refers to all relevant lookup tables. If multiple temperature constraint violations occur, the constraint lookup table associated with the first upstream temperature point overrides the effects of the lookup tables for temperature points downstream.

RESULTS

The FLC structure is currently able to provide control of several temperature processes in the Mach 8 System and in the Mach 6 System. Results for the Mach 6 High Reynolds Number Tunnel (M6HRNT) and the Nozzle Test Chamber (NTC) are presented to illustrate the ability of the FLC to accommodate different tunnels with widely varying operating conditions. The flow paths for operation of these tunnels are illustrated in Figures 1 and 2.

The M6HRNT is operated by first preheating through the trench until the desired pipe metal temperature is reached upstream of the tunnel. Process data from tunnel preheat with temperature and pressure under automatic control are plotted in Figure 4. While the flow path is to the trench, the FLC uses feedback from a trench air temperature measurement. The human operators observe the trench pipe temperature to decide when to end the pre-heat procedure The plots include relevant temperature measurements, trench pressure and FLC heater current command. The plots clearly show that while the trench temperature is brought up to the setpoint of 490 ^{O}F , the mixing-T differential temperature is kept below 200 ^{O}F, and the heater outlet temperature is kept well below the maximum limit of 900 ^{O}F. The trench pressure is increased during preheat in preparation for tunnel conditions of 1000 psia and 475 ^{O}F.

For this tunnel, after preheat is completed, the flow can be redirected to the tunnel through a hydraulic valve. When this is done, flow to the atmosphere through the trench is stopped by closing another hydraulic valve. These valves are interconnected such that when one is open the other is closed (refer to Figure 1). When flow is established to the tunnel, the FLC uses a settling chamber air temperature measurement as feedback. Switching between trench and settling chamber feedback measurements for the FLC is accomplished using signals which indicate the position of the interconnected valves and data from process feedback.

Process data from tunnel operation with temperature and pressure under automatic control, at a settling chamber pressure of 1000 psi and a settling chamber temperature setpoint of 475 ^{O}F, are plotted in Figure 5. The plots include pressure and temperature data for the trench and the settling chamber, as well as the FLC heater current command. The pressure transducer and thermocouple, which provide trench pressure and temperature data, are located upstream of the interconnected valves and are still in the flow path when flow to the tunnel is established. The transition from flow to the trench to flow through the tunnel is indicted in the pressure plot by the rise in settling chamber pressure from zero to 1000 psia. The large spike in the settling chamber temperature data is a result of rapidly pressurizing the settling chamber during the transition. The FLC does not respond to this spike, because the temperature feedback to the FLC is not switched from trench temperature to settling chamber temperature, until the settling chamber pressure rises to a 95% of the desired pressure setpoint. At this point in the transition, the temperature feedback is rapidly falling back to a value which is representative of the state of the temperature process during less energetic pressure transitions. The FLC is able to control the settling chamber temperature to within +/-1 ^{O}F of the desired setpoint of 475 ^{O}F. This provides suitable conditions for conducting aerodynamic research testing in the tunnel. Of particular interest is the response of the FLC to the temperature process as it approaches the setpoint. The heater current command rises from approximately 54.25% to 55% and stays at this command percentage for at least 10 seconds before the FLC makes another change. This corresponds to a condition, in which the FLC has identified the temperature process error as being "PosL" and the temperature rate as being "PosL", thus producing a change in the Heater command of "Zero" (refer to Table I). This action is representative of the "wait and see" response a human operator might provide when observing the settling chamber temperature approaching the setpoint. Such a response to these temperature process conditions would be impossible to provide using a PID algorithm, unless a complicated scheme using the if-then-else logic of the programming language could be employed.

Operation of the M6HRNT at lower settling chamber pressures may include switching between flow to the trench and flow to the tunnel and back again repeatedly. Process data for this mode of operation is plotted in Figure 6. This time the desired tunnel operating conditions are 500 psia at 425 ^{O}F. The times at which switching occurs is illustrated by the steep rise and fall of the settling chamber pressure. The data clearly shows the ability of the FLC to provide appropriate control of settling chamber temperature during this mode of tunnel operation. In this case, the FLC responds a little differently than in the case at 1000 psia, presented in Figure 5. The temperature plot shows that prior to switching from trench flow to tunnel flow , the settling chamber temperature is 12 ^{O}F below the desired settling chamber temperature of 425 ^{O}F for the first switch from trench to tunnel. When the switch occurs the temperature in the settling chamber overshoots to slightly above 430 ^{O}F due to the initial settling chamber temperature, and the FLC must reduce the heater command percentage to bring the temperature back to the setpoint. In the second switch from trench to tunnel, the settling chamber temperature is even closer to the desired settling chamber temperature prior to the switch. This case represents operation of the tunnel under conditions in which the metal temperature of the settling chamber is close to the desired setpoint. In the 1000 psia case, presented in Figure 5, prior to the switch from trench flow to tunnel flow, the settling chamber temperature is 50 ^{O}F lower than the desired settling chamber temperature for tunnel operation. Thus, the FLC is required to drive the temperature up to the setpoint.

The operation of the NTC also requires a preheat phase. In the case presented, flow is first established through valve 3213 to the trench, and then flow is directed to the tunnel through valve 3201 (refer to Figure 2). Preheat is performed until the tunnel settling chamber temperature reaches 250 ^{O}F. Process data from preheat of the NTC with pressure and temperature under automatic control is presented in Figure 7. Relevant temperature, settling chamber pressure and FLC heater current command data are plotted. The control of temperature in this case is extremely difficult. The operation of the tunnel at 50 psia requires considerably less flow than the minimum flow required to operate the heater. Thus, the majority of the flow from the heater, and the associated thermal energy, must be ejected to the trench through valve 3213 in order to provide low flow to the tunnel (refer to Figure 2). The plots of the temperature response show that the FLC is able to bring the settling chamber temperature to 250 ^{O}F with no violation of any temperature constraints.

After preheat is completed, the flow to the tunnel is stopped and subsequently resumed to provide appropriate conditions for conducting aerodynamic research in the tunnel. Process data of the NTC under automatic control for a typical sequence of tunnel operating conditions is plotted in Figure 8. The settling chamber temperature setpoint is 250 ^{O}F, and the pressure ranges from 50 psia to 175 psia. In this case, flow is first established through valve 3213, before flow to the tunnel is started. The plots include data for temperature, settling chamber pressure and FLC heater current command. Figure 8 shows that the FLC is able to bring the settling chamber temperature to approximately 250 ^{O}F for a settling chamber pressure of 50 psia and maintain the temperature within reasonable limits as the settling chamber pressure is increased to 75 psia. When the settling chamber pressure is increased to 75 psia, valve 3202 is opened to keep valve 3201 from opening to its maximum position. Valve 3202 is a very large valve in comparison with valve 3201, and must be opened carefully to prevent excessive overshoot of the desired pressure setpoint. Valve 3202 is operated manually, while valve 3201 is used to trim the settling chamber pressure under automatic control. In the plot of settling chamber pressure in Figure 8, the setpoint of 75 psia is exceeded by 25 psia in the transient response. The rapid increase in pressure serves to first increase and then decrease the settling chamber temperature. This disturbance upsets the settling chamber temperature sufficiently to cause the temperature to swing within +/- 8 ^{O}F of the desired setpoint while the FLC attempts to regulate the temperature. The FLC brings the settling chamber temperature back to within +/- 2 ^{O}F of the desired setpoint and is able to maintain the temperature within this band for the duration of the tunnel operation, except for the slight disturbance experienced when pressure is raised from 125 psia to 175 psia. The settling chamber temperature briefly reaches 254 ^{O}F at this point, but is returned to the setpoint in a reasonable amount of time. The series of four positive pressure spikes and two negative pressure spikes around a settling chamber pressure of 125 psia correspond to closing and opening bleed valves at the settling chamber.

Results are not presented for several other temperature processes that are under the control of the FLC. The FLC is used to control temperature for flow through valve 3203 to the trench during preheat operations for the Mach 6 Twenty Inch Tunnel (Refer to Figure 2). The FLC also provides control of the temperature for flow through valve 3170 to the trench and for flow through valve 3213 to the trench. This operation is frequently performed while flow is directed through these valves prior to establishing flow to the tunnel in operation.

SUMMARY

A FLC algorithm is successfully applied to the control of temperature processes for the operation of wind tunnels in the Hypersonic Blowdown Tunnels Building at NASA's Langley Research Center. The algorithm is routinely used in the automatic control of temperature processes for the M6HRNT, the NTC and several other temperature processes. The operation of the M6HRNT or any tunnel in the Mach 8 system could include the use of valve 3170, thus requiring monitoring of the 3170 trench temperature in addition to the heater outlet temperature, mixing-T air temperature and the mixing-T metal temperature. Therefore, the FLC must simultaneously monitor up to four temperature points along the flow path and maintain these processes within safety constraints, while providing closed loop control of a trench temperature or a settling chamber temperature. The results presented for the M6HRNT illustrate the monitoring of three points along the flow path during control of the trench temperature or settling chamber temperature. The results presented for the NTC illustrate the monitoring of two temperature points in addition to the control of settling chamber temperature.

The FLC algorithm is implemented in control system software designed to control air distribution to six research tunnels. The algorithm is made flexible through the use of normalized fuzzy sets and scaling factors for the temperature process error, the temperature process rate and the incremental command output. If required, these scaling factors are scheduled based on settling chamber pressure feedback to accommodate changing process dynamics in a particular tunnel. This flexibility provides a means of applying a common algorithm to the control of temperature in tunnels with widely varying operating conditions.

Application of the FLC to the control of temperature for all the tunnels supplied by the High Pressure Air Distribution System is the ultimate goal of this effort. Tests conducted with the FLC providing automatic control of temperature process for the Half-meter Quiet Tunnel (1/2MQT) and the Mach 6 Twenty Inch Tunnel (M6-20inT) indicate the need for additional fuzzy control tables and gain scheduling, respectively. These enhancements to the algorithm will provide the additional abilities needed to handle the special cases specific to the operation of these tunnels. The enhancements will be included in the common FLC structure to facilitate the use of the additional abilities for the control of other tunnels, as required.

REFERENCES

[1] P. J. King and E. H. Mamdani, "The Application of Fuzzy Control Systems to Industrial Processes," *Automatica*, Vol. 13, pp. 235 - 242, 1977.
[2] E. Cox, "Fuzzy Fundamentals," *IEEE Spectrum*, Vol. 29, No. 10, pp 58 - 61, October 1992.
[3] C. C. Lee, "Fuzzy Logic in Control Systems, parts 1 and 2," *IEEE Transactions on Systems, Man and Cybernetics*, Vol. 20 , No. 2, pp.404-434, March/April 1990.
[4] B. Kosko, *Neural Networks and Fuzzy Systems*, Englewood Cliffs, New Jersey: Prentice Hall, 1992.

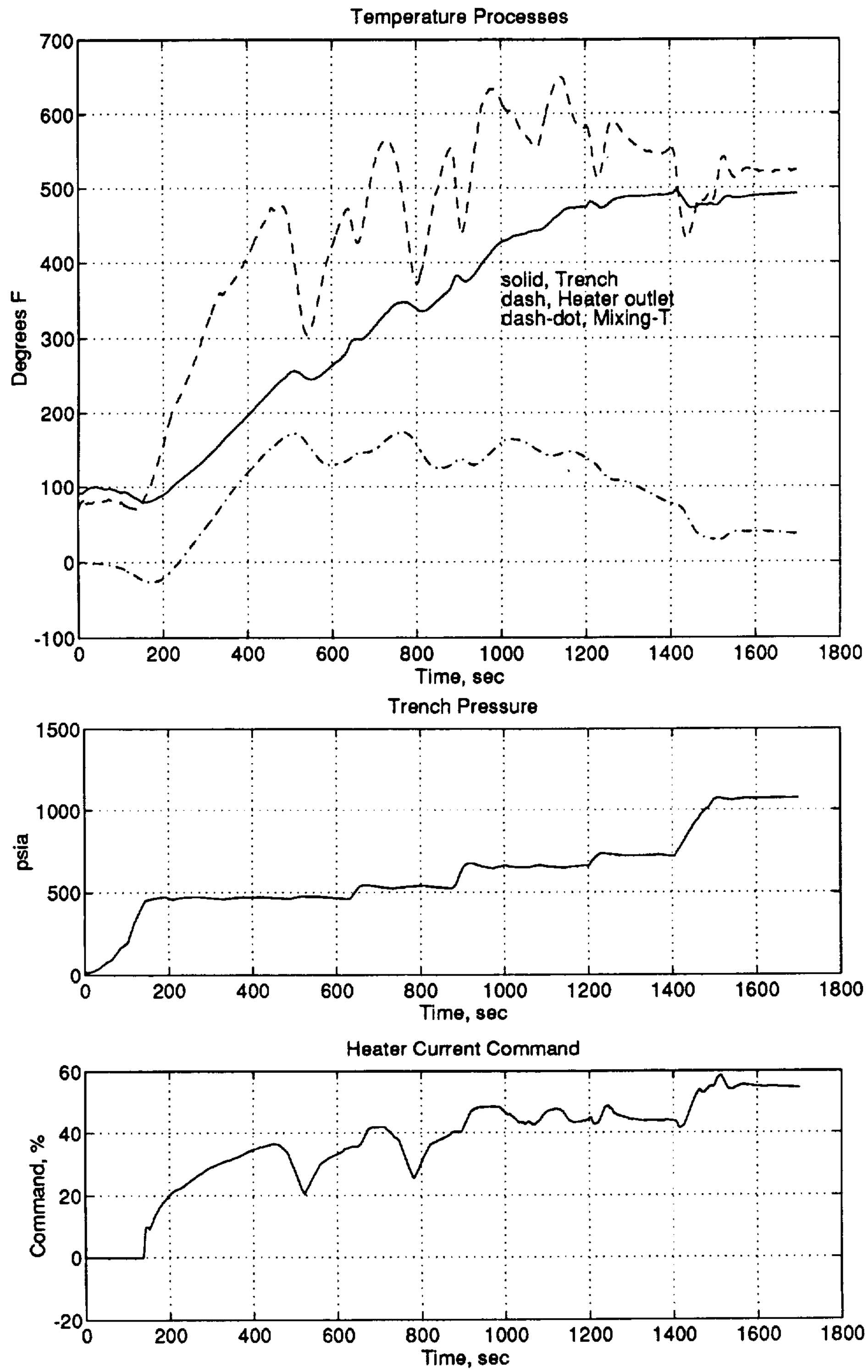

Figure 4. M6HRNT Pre-Heat Process Data

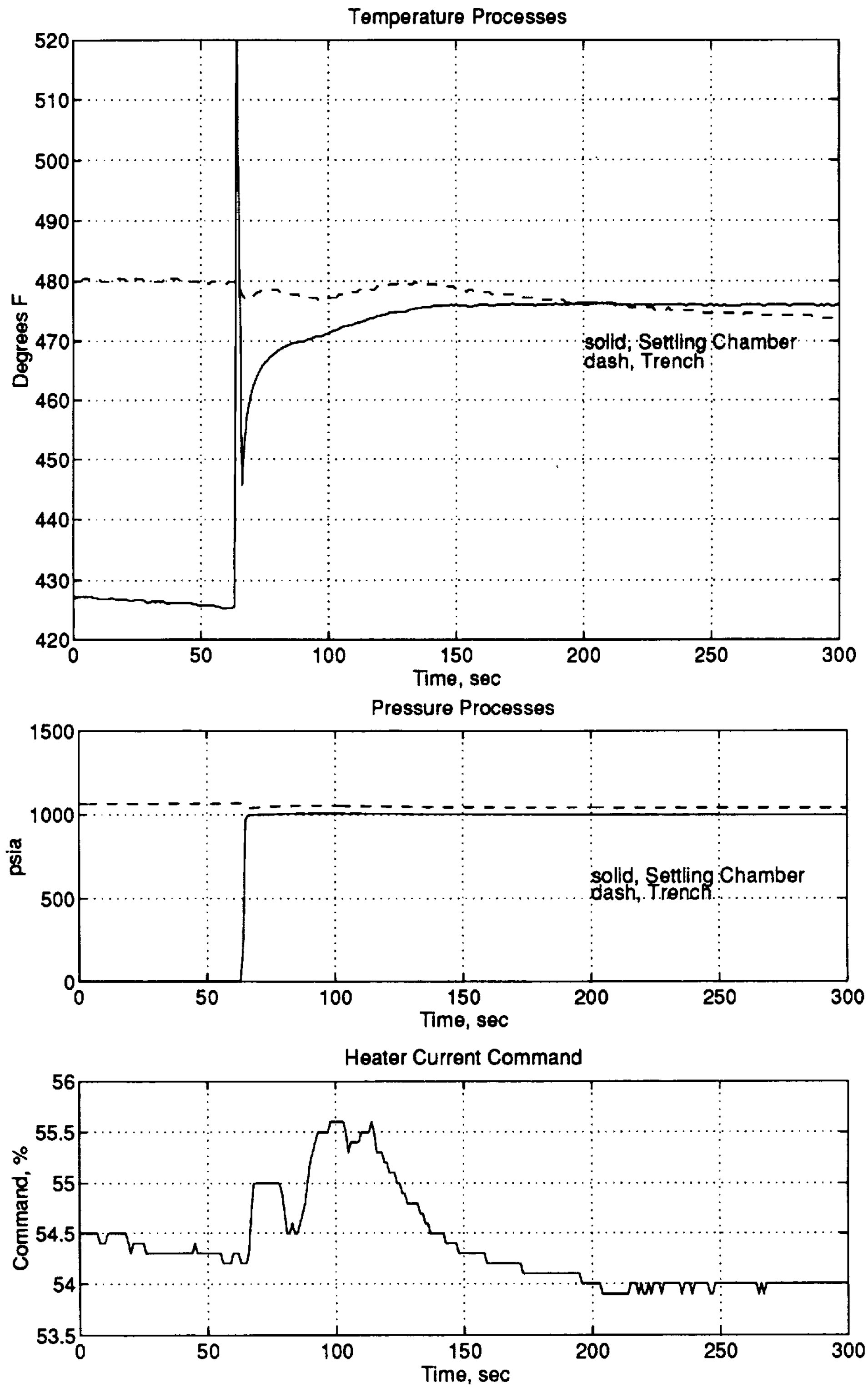

Figure 5. M6HRNT Tunnel Process Data at 1000psia

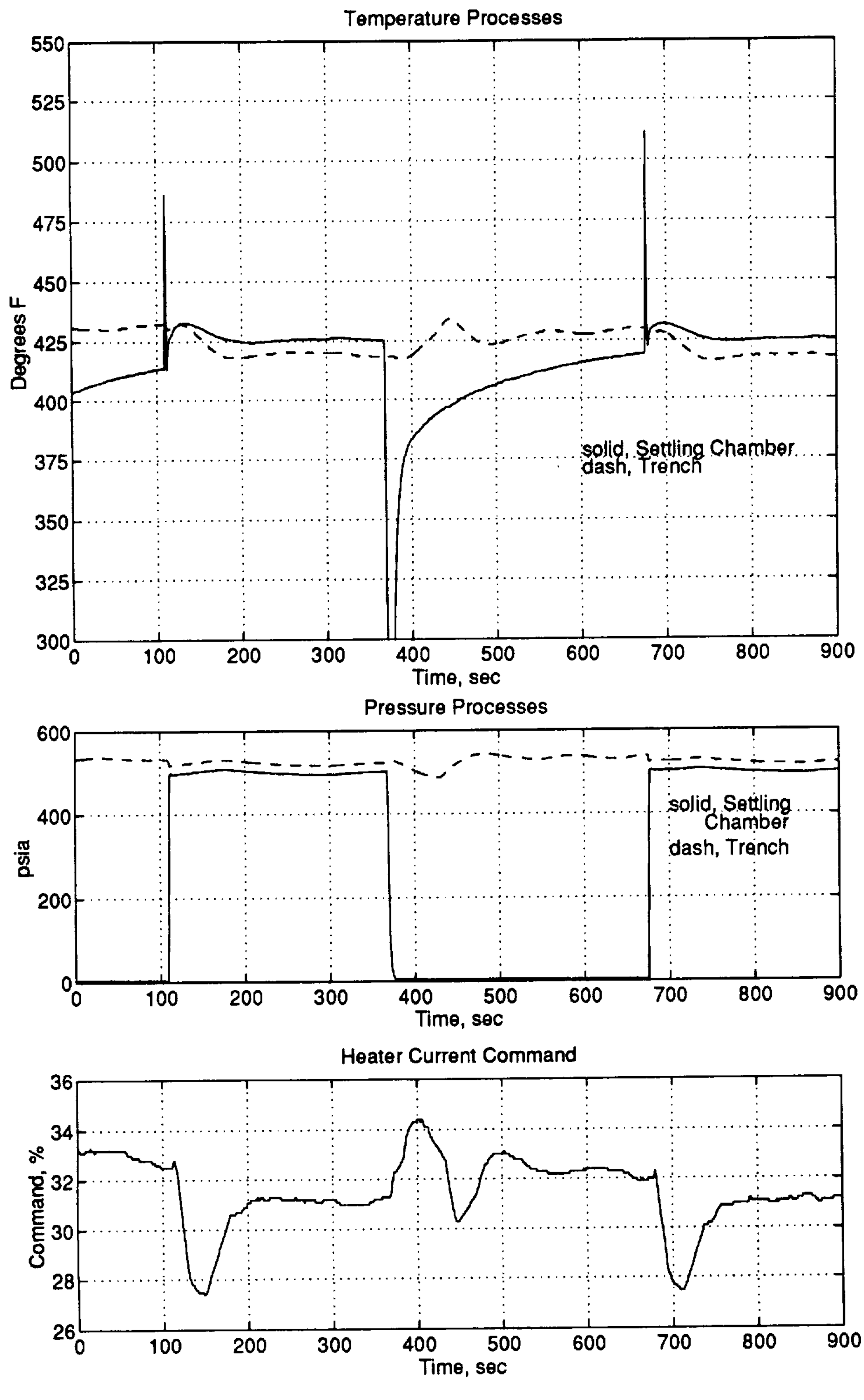

Figure 6. M6HRNT Process Data at 500 psia

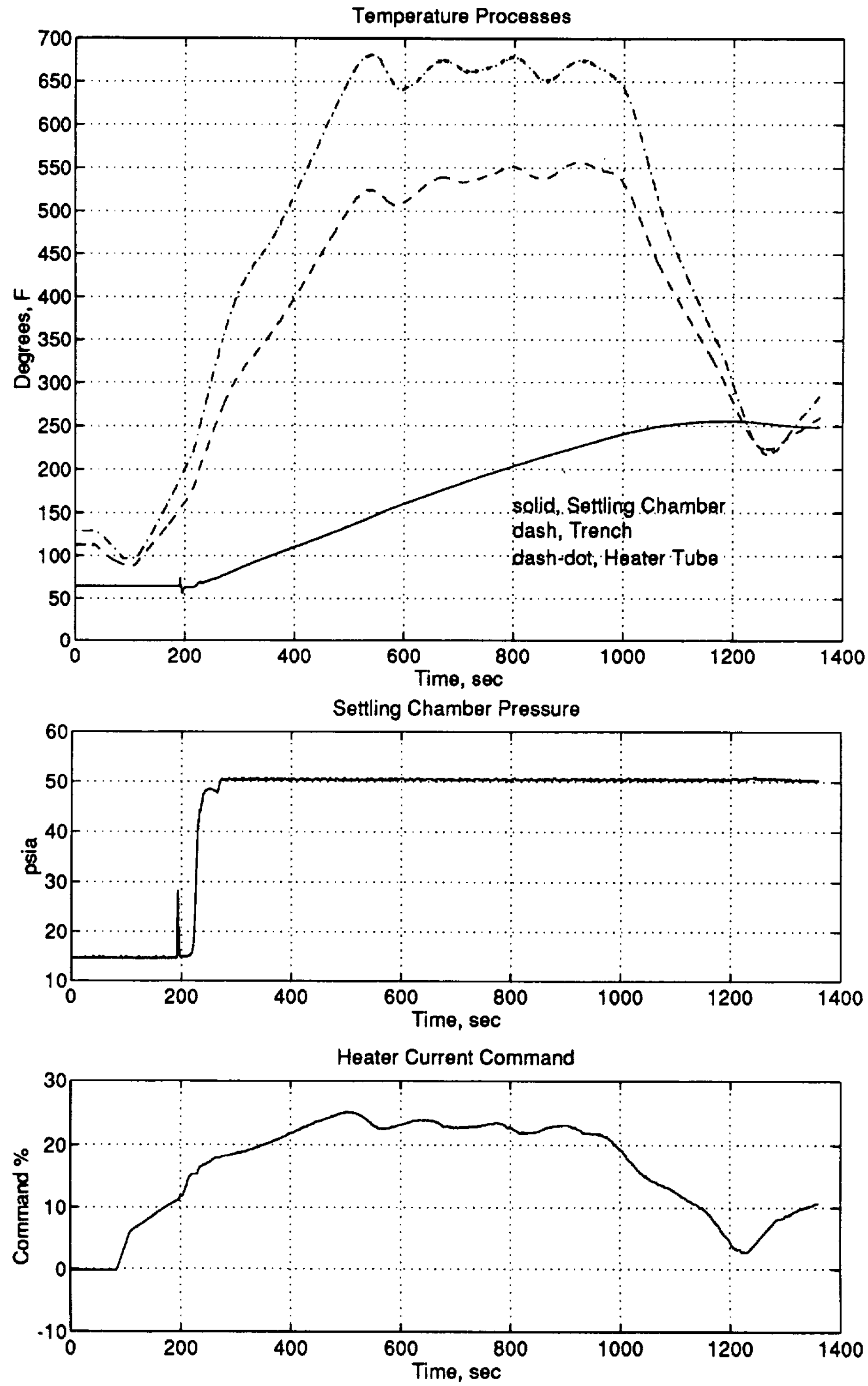

Figure 7. NTC Preheat Process Data

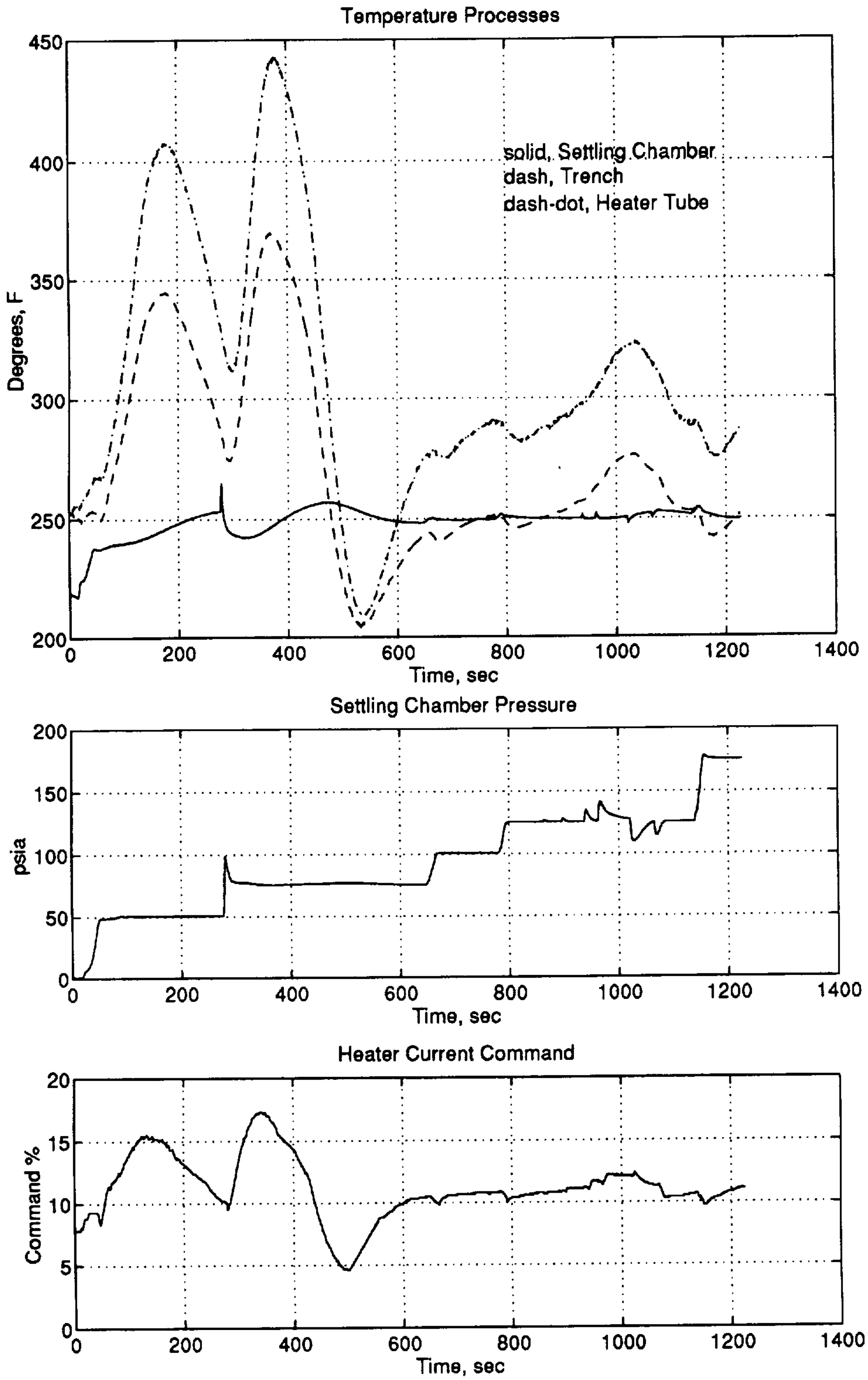

Figure 8. NTC Process Data

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 1994	Technical Memorandum

4. TITLE AND SUBTITLE
Application of Fuzzy Logic to the Control of Wind Tunnel Settling Chamber Temperature

5. FUNDING NUMBERS
505-70-59-03

6. AUTHOR(S)
David A. Gwaltney
Gregory L. Humphreys

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, Virginia 23665-0001

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
NASA TM-109105

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 09

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)
The application of Fuzzy Logic Controllers (FLC's) to the control of nonlinear processes, typically controlled by a human operator, is a topic of much study. Recent application of a microprocessor-based FLC to the control of temperature processes in several wind tunnels has proven to be very successful. The control of temperature processes in the wind tunnels requires the ability to monitor temperature feedback from several points and to accommodate varying operating conditions in the wind tunnels. The FLC has an intuitive and easily configurable structure which incorporates the flexibility required to have such an ability. The design and implementation of the FLC is presented along with process data from the wind tunnels under automatic control.

14. SUBJECT TERMS
Fuzzy logic application; Wind tunnel temperature control

15. NUMBER OF PAGES
16

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited