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Temperature Distortion Generator for Turboshaft Engine Testing

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SUMMARY

The procedures and unique hardware used to conduct an experimental investigation into the response of a small-turboshaft-engine compression system to various hot gas ingestion patterns are presented. The temperature distortion generator described herein uses gaseous hydrogen to create both steady-state and time-variant, or transient, temperature distortion at the engine inlet. The range of transient temperature ramps produced by the distortion generator during the engine tests was from less than 111 deg K/sec (200 deg R/sec) to above 611 deg K/sec (1100 deg R/sec); instantaneous temperatures to 422 deg K (760 deg R) above ambient were generated. The distortion generator was used to document the maximum inlet temperatures and temperature rise rates that the compression system could tolerate before the onset of stall for various circumferential distortions as well as the compressor system response during stall.

INTRODUCTION

When rotary-wing aircraft hover near the ground, the hot engine exhaust gas can be recirculated into the engine inlet by the rotor downwash (fig. 1). This reduces the power available (refs. 1 to 3) and the compression system stall margin (refs. 1 and 3). This effect is similar to that encountered when gun or rocket exhaust gases are ingested. Although the reingestion phenomenon is reasonably well understood, the confident prediction of reingestion levels for any arbitrary helicopter/engine design and their effect on engine performance requires a comprehensive set of design data not currently available (ref. 3). Typically, model and flight tests have been conducted to measure the magnitude and effects of this ingestion (ref. 3).

The research work reported herein and in reference 4 is one step toward a better understanding of the response of a typical small turboshaft engine to hot-gas ingestion in the controlled environment of a ground-level test facility. A temperature distortion device, consisting of a gaseous hydrogen burner with individually controlled 45° sectors, was installed upstream of an engine

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inlet to create various steady-state and transient temperature distortion patterns. The engine was instrumented with steady-state and high-response probes to record engine inlet conditions and engine response. The range of the transient temperature ramps was from less than 111 deg K/sec (200 deg R/sec) to above 611 deg K/sec (1100 deg R/sec); instantaneous temperatures to 422 deg K (760 deg R) above ambient were generated, as determined from the high-response temperature data at the engine inlet. Stall and no-stall conditions were produced at various engine power settings.

APPARATUS

Engine

The engine (fig. 2) that was used with the temperature distortion generator was a front-drive, turboshaft engine consisting of an integral particle separator; a single-spool gas generator section consisting of a five-stage axial-flow, single-stage centrifugal-flow compressor, a throughflow annular combustor, and a two-stage axial-flow gas generator turbine; and a free two-stage axial-flow power turbine.

Instrumentation

The instrument station locations and the distribution of high-response instrumentation at the engine inlet are shown in figure 3. The engine compression system was also heavily instrumented with high-response and steady-state pressure instrumentation to record the response of the compressor to inlet temperature distortion. The thermocouple calibration procedure is described in the appendix.

Test Facility

The temperature distortion generator and engine were run in a ground-level test facility. The facility has an atmospheric inlet and atmospheric, as well as altitude, exhaust capability (fig. 4). The hardware required to support the testing included an eddy-current dynamometer rated at 1640 kW (2200 hp), a gearbox with a 3.743 gear ratio, an inlet bellmouth, an airflow measurement spool piece, and a device to measure airflow dumped overboard through the scavenge blower on the engine.

Temperature Distortion Generator

The temperature distortion generator can create both steady-state and time-variant, or transient, temperature distortion at the engine inlet by using gaseous hydrogen. It is an adaptation of a device described in reference 5. The burner (fig. 5) consists of eight individually controlled sectors, with three swirl cup combustors (fig. 6) per sector. Not shown are stainless steel straps that were installed between the cups in each sector to aid flame propagation.

The hydrogen system supplied gaseous hydrogen fuel to the eight-zone burner. The system schematic is shown in figure 7. Since each zone could be controlled individually, the burner could be operated in many combinations of single and multiple zones. For safety, the engine was required to be running at or above idle speed for distortion burner operation. The system was operated from the control room at cabinet 14, which is described in figure 8.

The gaseous hydrogen was supplied from portable K-bottles connected to a three-bottle manifold located at the trailer pad (fig. 7(a)). If more gaseous hydrogen was needed than could be supplied by the K-bottles, the system could also be supplied by a 1982-m^3, 16.5-mPa (70 000-ft^3, 2400-psig) capacity tube trailer by changing the hardware at the bottle manifold.

The gaseous hydrogen supply was filtered and the pressure was regulated near the storage area. The gaseous hydrogen was filtered to 5 micrometers absolute. A differential pressure switch (FH106) was used to monitor the condition of the filter and would initiate an annunciator alarm at 138 kPa (20 psid). Two dual-diaphragm pressure regulators (FH108 and FH109) reduced the K-bottle supply pressure to 2100 and 965 kPa (300 and 140 psig), respectively, and maintained the system line pressure at 965 kPa (140 psig). The gaseous hydrogen was delivered to building shutoff valve FH118 (located outside the cell wall) by 19 x 1.7 mm (3/4 x 0.065 in.) stainless steel tubing. The gaseous hydrogen flow rate to the test cell was measured by venturi FH116, which also limited the flow to a maximum of 0.224 m^3/sec (475 ft^3/sec).

Inside the test cell (fig. 7(b)), the gaseous hydrogen supply was controlled by the main burner flow control and shutoff valves (FH119 and FH122) and the pilot flow control and shutoff valves (FH123 and FH124), which were installed in parallel.

Gaseous hydrogen was delivered to each of the eight zones through 6.4-mm (1/4-in.) stainless steel tubing and the eight remotely operated supply valves (FH141 to FH148). A spark plug in each zone was the ignition source. Individual temperatures were controlled by the eight remotely operated throttling valves (FH125 to FH132). A thermocouple in each zone provided remote temperature indication. Once a zone was lit, an annunciator alarm would sound if the temperature fell below 478 K (860 °R) (indicating a flameout); in addition, the gaseous hydrogen supply valve (or valves) would close and the zone purge valve (or valves) would open.

The system can create transient temperature ramp rates to 1666 deg K/sec (3000 deg R/sec) in single- or multizone patterns. Less intense ramps were run during the actual engine tests because the engine always stalled before the system capability was reached. During transient operation of the system, a steady-state pattern was first set up through the main burner flow control valve by using the zone supply and throttle valves. The flow was then pulsed by quickly opening and closing the pilot valve to ramp the preset temperature pattern up and down, a "spike." The magnitude of the spike was gradually increased by presetting the flow control valve at increasingly open positions until onset of engine stall.

Temperature profiles at the engine inlet were measured by five-point cantilevered thermocouple rakes (fig. 3), which were located two duct diameters downstream of the burner. These temperatures were observed in the control room on a 50-channel bar graph display.

The entire hydrogen system was purged once before each test run and once after each test run with gaseous nitrogen. A hand-operated valve (N212), located near the trailer pad, supplied gaseous nitrogen to the system at 1 MPa (150 psig). The gaseous hydrogen supply line was purged through the zone throttling valves (FH125 to FH132) and discharged through the cell vent valve (FH166) to the roof vent. Inside the cell, the eight gaseous hydrogen zone supply lines and the eight burner zones were purged through valves N231 to N238. The purged gas was then vented through the engine and out the facility exhaust system. Since the electric actuators of the throttle, supply, and purge valves were not rated for operation in hazardous locations, these actuators were enclosed in a gaseous nitrogen atmosphere.

The hydrogen system setup and shutdown, operation, and safety control logic was implemented by using a process controller (PC). The PC took a permissive role during setup and shutdown of the system to ensure that these steps were taken in a safe order. The PC could also aid in troubleshooting because it could quickly pinpoint problems. During operation of the system, each of the eight zones was controlled by a separate set of logic although any number of zones could operate together in the multizone mode. The diagram in figure 9 describes the zone operation.

A systems hazards analysis indicated that three recovery action sequences, or system shutdowns (table I), should be controlled by the PC. Temperature and pressure sensors were used to monitor critical system parameters. The PC implemented the safety control logic on the basis of the severity of a sensed out-of-limit condition. Another circuit was used to sense out-of-limit engine and facility parameters and to initiate emergency shutdown procedures independently of the PC; this included placing the gaseous hydrogen burner in the power-off, fail-safe position.

Table II contains checklists for gaseous hydrogen bottle connection, burner operation, and system purge and shutdown. Table III describes in detail the hardware used in the system.

CONCLUDING REMARKS

In summary, the temperature distortion effects of hot-gas ingestion in small turboshaft engines can be simulated by using the gaseous hydrogen temperature distortion generator. It is a versatile device that can be used to simulate a large variety of steady-state and transient temperature distortion patterns. The system can be duplicated by using the hardware and procedural information provided.

APPENDIX - CALIBRATION OF THERMOCOUPLE PROBE USED FOR TESTS OF SMALL TURBOSHAFT ENGINES

This appendix briefly describes the calibration of a Chromel-Alumel thermocouple probe used during tests of small turboshaft engines. The purpose of this writeup is to acquaint others with a general thermocouple calibration procedure and also to present specific time-constant data for a certain thermocouple probe. A schematic view of the probe is included in this appendix as figure 10.

The calibration, performed in a ground-level test cell, consisted of acquiring the necessary data to calculate the time constant τ_0 for the Chromel-Alumel thermocouple. The time constant of a system is usually defined as the time required for the system to reach 63.2 percent of its steady-state value (ref. 6). The value of 63.2 percent comes from the fact that many time-varying functions can be represented by the exponential relation

$$T = (T_1 - T_0)e^{-t/\tau} + T_0 \tag{1}$$

where t is the time variable, T_1 is an initial excited state, τ is a constant, and T_0 refers to the steady-state value of T (when t approaches ∞). When $t = \tau$, equation (1) becomes

$$T = (T_1 - T_0)e^{-1} + T_0 = 0.368\ (T_1 - T_0) + T_0 \tag{2}$$

In other words, when $t = \tau$, the difference between T and T_1 is 63.2 percent of the difference between the initial and the steady-state values of T. This situation is displayed in figure 11.

The procedure used to obtain the time constant of the probe in this investigation was quite simple. The experimental setup is shown in figure 12 (a modification of a figure from ref. 7). Here the probe, mounted to receive flow from a nozzle, was heated to an initial excited state by a hot-air blower. While being heated, the thermocouple was protected from the ambient conditions of the nozzle flow by a simple shield. Once the thermocouple achieved equilibrium in the excited state, the shield and the hot-air source were pneumatically removed at the same instant, and the thermocouple was exposed to the air flowing from the nozzle.

The response of the excited thermocouple to the nozzle flow is recorded on both a digital voltmeter and a strip-chart recorder. The voltmeter readings are necessary to calibrate the strip chart. An example strip-chart recording is shown in figure 13 (from ref. 8). The time constant of the probe τ is measured as the recorded time required to reach 0.368 x $(T_1 - T_0)$ on the temperature scale. The value of τ will vary with respect to various nozzle flow conditions and initial thermocouple temperatures. Reference 2 suggests using the following expression to calculate a reference time constant τ_0:

$$\tau_0 \simeq \tau \sqrt{\frac{Mp}{P_0}} \left(\frac{T_1}{T_0}\right)^{0.18} \tag{3}$$

where

τ measured time constant, sec

M stream Mach number

p stream static pressure, psia

p_0 reference static pressure, 0.704 kPa (14.696 psia)

T_i probe indicated temperature, °R

T_0 reference temperature, 555 K (999 °R)

This time constant should remain a constant for a particular probe over a wide range of flow and initial temperature conditions.

The time constant values calculated for the T700 probe are displayed in table IV, and again, figure 10 shows the probe design. The time constants for the probe were measured and then averaged from three runs performed over each of six Mach number conditions. Within each three-run set the measured time constants showed very close agreement. Between the sets the time constant values increased as expected with each decrease in flow Mach number. Apparently, the reference time constant equation became invalid for stream Mach numbers of 0.10 or less, but a fairly steady value of τ_0 was found over the Mach number range 0.15 to 0.40. This value could possibly remain constant beyond the 0.40 Mach number condition, but the calibration was based on expected flow conditions in the engine tests, which did not exceed Mach 0.40.

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TABLE I. - GASEOUS HYDROGEN SYSTEM SHUTDOWNS

Shutdown sequence	Cause	Results
1	Manual pushbutton Line pressure switches (F112 (F113) out of limits	Annuciator alarm Trailer supply valve closes Building supply valve (FH118) closes Cell line vent valve (FH166) opens, venting line in cell to zero All zone supply valves close Zones are automatically purged and then shut off manually
2	Engine dropping below idle Manual pushbutton or key switch Sequence 1 shutdown Gaseous nitrogen supply pressure low (N208 and N220) Low flow of gaseous nitrogen purge for electric valves in cell (N228)	The same as for sequence 1 except that the trailer valve does not close
3	Zone temperature dropping below limit	Annunciator alarm Zone gaseous hydrogen supply valve closes Zone purge is started and must be manually turned off

TABLE II. - CHECKLISTS

T-700 ENGINE PROGRAM

SIGN OFF .... GROUP NO. 7

GH2 BOTTLE CONNECTION
....

NOTE E.S. AND S1 MUST BE SATISFIED (CO2 , HYD. OIL, EXH. FAN, V42 OPEN, LOUVERS OPEN)

.... OBTAIN KEY FOR PURGE VALVE N212 (ECRL KEY BOX)

.... LOCATE 2 MEN AT THE TRAILER WITH WALKIE TALKIES.
NOTE WALKIE TALKIES MUST REMAIN 25 FT FROM THE TRAILER.

.... BLOCK OFF THE AREA WITH THE APPROPRIATE BARRICADES AND STROBE LIGHTS.

.... CHECK MAIN GN2 SUPPLY VALVE AT BOTTLE FARM IS OPEN.

.... SET UP AND CONNECT GH2 K-BOTTLES.

.... UNLOCK PURGE HAND VALVE N212.

.... OPEN HIGH PRESSURE GN2 SUPPLY HAND VALVE N202.

.... CHECK PR. REG. N203 SET AT 60 PSIG.

.... CHECK THAT PR. REG. N209 SET AT 100 PSIG.

.... CHECK THAT PR. REG. N213 SET AT 350 PSIG.

.... CHECK THAT LOADERS N214 AND N217, FOR PR. REG. FH108 AND FH109 , ARE BACKED OFF TO ZERO ON GAGES N215 AND N218.

.... OPEN PURGE HAND VALVE N212.

.... OPEN GAGE HAND VALVE FH102 AND CHECK PURGE PRESS. ABOUT 100 PSI ON GAGE FH103.

.... OPEN THE MAIN MANIFOLD HAND VALVE FH101.

.... OPEN THE GH2 MANIFOLD HAND VALVE USED FOR PURGING.

.... CHECK GH2 PANEL POWER KEY SWITCH IS ON.

.... OPEN TRAILER REMOTE SHUTOFF VALVE AND PURGE 30 SECS. THE SWITCH MUST BE HELD IN SINCE THERE IS NO LINE PRESSURE.

.... CLOSE THE GH2 MANIFOLD HAND VALVE USED FOR PURGING.

.... OPEN BURNER PILOT SHUTOFF VALVE FH124

.... OPEN BLDG. GH2 SHUTOFF VALVE FH118.

.... CHECK CELL VENT VALVE FH166 IS OPEN.

.... OPEN MAIN GH2 FLOW CONTROL VALVE FH119 FULL OPEN.

.... OPEN GH2 PILOT FLOW CONTROL VALVE FH123 TO 30 PSIG.

.... OPEN HIGH FLOW SHUTOFF VALVE FH122.

.... OPEN SYSTEM VENT VALVE FH111.

.... LOAD PR. REG FH108 TO 325 PSIG WITH LOADER N214.

.... LOAD PR. REG. FH109 TO 140 PSIG WITH LOADER N217.

.... PURGE FOR 2 MIN.

TABLE II. - Continued

.... OPEN AND CLOSE FH111 TO PURGE BOTH VENT STACKS.

.... OPEN AND CLOSE FH122 TO ASSURE BOTH LEGS ARE PURGED. LEAVE FH122 OPEN.

.... CLOSE PURGE HAND VALVE N212 AND LOCK.

.... LET REMAINING N2 VENT AND THEN CLOSE FH111.

.... OPEN CELL VENT LINE PURGE VALVE N222 AND PURGE FOR 30 SECS.

.... CLOSE CELL VENT LINE PURGE VALVE N222.

.... CLOSE BUILDING SHUTOFF VALVE FH118.

.... CLOSE FH119 AND FH123.

.... CLOSE FH124 AND FH122.

.... CHECK THAT VENT VALVE FH111 IS CLOSED.

.... OPEN GH2 BOTTLE HAND VALVES ALL THE WAY.

.... PRESSURE CHECK THE BOTTLE CONNECTIONS WITH LEAK-TEK.

.... IF NO LEAKS, OPEN THE BOTTLE MANIFOLD HAND VALVES.

.... OPEN THE TRAILER REMOTE SHUTOFF VALVE.
HOLD THE SWITCH IN UNTIL THE LINE PRESSURE IS ABOVE 50 PSIG.

.... BOTTLE CONNECTION IS COMPLETE AND THE GH2 SYSTEM IS NOW READY FOR CONTROL ROOM OPERATION.

GH2 BURNER OPERATION
....

NOTE THIS PORTION OF CHECK SHEETS MAY NOT BE DONE UNLESS THE ENGINE IS ROTATING AT IDLE OR ABOVE

.... RESET GH2 SUPPLY SYSTEM SHUTDOWN.

.... CLOSE CELL VENT VALVE FH166.

.... CHECK THAT TRAILER REMOTE SHUTOFF VALVE IS OPEN.

.... CHECK THAT GH2 FLOW CONTROL VALVES FH119 AND FH123 ARE UNLOADED CLOSED.

.... OPEN BUILDING SHUTOFF VALVE FH118.

.... OPEN THE PILOT SHUTOFF VALVE FH124.

NOTE THE FOLLOWING PERMISSIVES MUST BE SATISFIED.

.... GH2 PANEL KEY SWITCH IS ON.

.... GH2 LINE PRESSURE IS WITHIN LIMITS.

.... EINGINE IS AT OR ABOVE IDLE.

SINGLE ZONE OPERATION
....

START UP
....

.... OPEN AND CLOSE FH166 TO VENT THE PRESSURE TRAPPED IN THE SUPPLY LINE.

.... CHECK FH124 IS OPEN.

.... CRACK OPEN REGULLATOR FH123, ABOUT 5 PSIG ON LOADER.

.... PLACE MODE SELECT ON SINGLE ZONE.

.... INITIATE ZONE PURGE ON.

.... ALLOW PURGE FOR 10 SECS.

.... INITIATE ZONE IGNITION. BURNER STATUS IS ON.
SIMULTANEOUSLY, OPEN REGULATOR FH123 TO ABOUT
20 PSIG ON LOADER.

IGNITION WILL COME ON FOR 10 SECS. IF NO LIGHT
IGNITION WILL GO OFF AND PURGE WILL COME ON. MANUALLY
TURN OFF PURGE AFTER 10 SECS.

SHUTDOWN
....

.... TO TURN OFF A ZONE, CLOSE ZONE GH2 SUPPLY VALVE AND
AFTER 15 SEC. CLOSE THE PURGE SUPPLY VALVE.

MULTI-ZONE OPERATION
....

START UP
....

.... OPEN AND CLOSE FH166 TO VENT THE PRESSURE
TRAPPED IN THE SUPPLY LINE.

.... CHECK FH124 IS OPEN.

.... CRACK OPEN REGULLATOR FH123, ABOUT 5 PSIG ON LOADER.

.... PLACE MODE SELECT BUTTON IN MULTIZONE OPERATION.

.... ENERGIZE ZONE IGNITION FOR DEZIRED ZONES.
BURNER STATUS READY

.... PUSH PURGE BUTTONS FOR DESIRED ZONES.
(PURGE EACH ZONE 10 SECS. MIN.)

.... PUSH MULTI-ZONE START BUTTON ON.
SIMULTANEOUSLY, OPEN REGULATOR FH123 TO ABOUT
20 PSIG ON LOADER.

SHUTDOWN
....

.... PUSH THE BURNER CONTROL STOP BUTTON ON.

.... CLOSE ALL ZONE GH2 SUPPLY VALVES.

.... AFTER 15 SECS. CLOSE ALL ZONE PURGE SUPPLY VALVES.

NOTE SHOULD ANY SINGLE ZONE NOT LIGHT DURING A
MULTI-ZONE IGNITION, CLOSE THAT ZONE,S GH2 FEED VALVE
AND AFTER 15 SECS., CLOSE THAT ZONE,S PURGE VALVE.
TO LIGHT THAT ZONE, FOLLOW THE SINGLE ZONE PROCEDUR

BURNER SHUTOFF AND SYSTEM VENT
....

NOTE ENGINE STILL AT IDLE OR COLD PIPE AIR FLOW
AT 4 LBS. PER SEC. OR ABOVE.

.... CLOSE PILOT SUPPLY VALVE FH124 IF IT IS OPEN.

.... CLOSE MAIN BURNER SUPPLY VALVE FH122.

.... THE ZONE FLAMES WILL GO OUT AND THE ZONE PURGES WILL COME ON. ALLOW ZONES TO PURGE FOR 15 SECS. AND THEN CLOSE THE PURGE VALVES.

.... LOAD FH119 TO FULL OPEN POSITION.

.... LOAD FH123 TO 30 PSIG.

.... CLOSE THE GH2 TRAILER REMOTE SHUTOFF VALVE.

.... OPEN THE BUILDING LINE VENT VALVES FH111 AND FH166 AND VENT THE SYSTEM TO ZERO.

GH2 SYSTEM PURGE AND SHUTDOWN
....

.... STATION 2 MEN AT THE TRAILER WITH WALKIE-TALKIES.

NOTE WALKIE TALKIES MUST REMAIN 25 FT. FROM TRAILER

.... CLOSE THE BOTTLE HAND VALVES.

.... CHECK FH119 FULL OPEN AND FH123 LOADED TO 30 PSIG.

.... CHECK FH111 AND FH166 OPEN.

.... OPEN THE TRAILER REMOTE SHUTOFF VALVE (HOLD IN THE SWITCH FOR 10 SECS.) TO VENT THE REMAINING PRESSURIZED GH2 THROUGH FH111.

.... CHECK THAT THE TRAILER REMOTE SHUTOFF VALVE IS CLOSED

.... CHECK THAT ALL 8 ZONE THROTTLE VALVES ARE OPEN.

.... CHECK FH124 IS OPEN.

.... CHECK FH118 IS OPEN.

.... CHECK FH166 IS OPEN.

.... OPEN PURGE HAND VALVE N212 AND PURGE FOR 2 MINS.

.... OPEN AND CLOSE HIGH FLOW SHUTOFF VALVE FH122 TO ASSURE BOTH LEGS ARE PURGED AND LEAVE OPEN.

.... OPEN AND CLOSE FH111 SEVERAL TIMES DURING PURGE.

.... CLOSE PURGE HAND VALVE N212.

.... LET REMAINING N2 VENT AND THEN CLOSE SYSTEM VENT VALVE FH111.

.... OPEN VENT LINE PURGE VALVE N222 AND PURGE FOR 1 MIN.

.... CLOSE VENT LINE PURGE VALVE N222.

.... CLOSE BURNER VALVES FH124 & FH122.

.... CLOSE CELL GH2 SHUTOFF VALVE FH118.

.... UNLOAD GH2 FLOW CONTROL VALVE FH119 TO ZERO.

.... UNLOAD FH123 TO ZERO.

.... BACK OFF LOADER N214 TO ZERO TO CLOSE FH108.

.... BACK OFF LOADER N217 TO ZERO TO CLOSE FH109.

.... CHECK LINE PRESSURE AT ZERO ON GAGE FH103 BY OPENING GAGE HAND VALVE FH102. CLOSE FH102.

TABLE II. - Concluded

.... CRACK OPEN THE BOTTLE MANIFOLD PURGE HAND VALVE.

.... OPEN PURGE HAND VALVE N212.

.... OPEN THE TRAILER REMOTE SHUTOFF VALVE AND PURGE FOR 30 SECONDS. THE SWITCH MUST BE HELD IN SINCE THERE IS NO LINE PRESSURE.

.... CLOSE PURGE HAND VALVE N212 AND LOCK.

.... CLOSE THE BOTTLE MANIFOLD PURGE HAND VALVE.

.... CLOSE THE GH2 SUPPLY HAND VALVE FH101.

.... CLOSE THE BOTTLE MANIFOLD HAND VALVES.

.... CLOSE THE GN2 HIGH PRESSURE SUPPLY VALVE N202.

.... TURN OFF THE GH2 PANEL POWER KEY SWITCH.

.... REMOVE THE BARRICADES.

.... REMOVE AND STORE THE GH2 BOTTLES AND THE STROBE LIGHTS.

TABLE III. - HARDWARE

ITEM NO.	DESCRIPTION	MFGR.	MODEL	SIZE	W.P. PSIG	REMARKS AND/OR NASA STOCK NO.
FH-100-A	HAND VALVE	REGO		3/8	3200	
FH-100-B	HAND VALVE	REGO		3/8	3200	
FH-100-C	HAND VALVE	REGO		3/8	3200	
FH-100-D	GLOBE VALVE	POWELL		3/8	3000	
FH-101	GLOBE VALVE			1/4	3000	4820-00-879-5827
FH-102	GLOBE VALVE			1/4	3000	4820-00-275-9321
FH-103	PRESS GAUGE	ASHCROFT	1279TAS	1/2	3000	WEATHER TIGHT, 4-1/2" DIAL RANGE 0-3000 PSI
FH-104	CHECK VALVE	NUPRO	SS-4C-10	1/4	3000	CV=.47, 1/4 SWAGELOK
FH-105	FILTER	PALL TRINITY	MEN9001-G24 MCS-1001-EE	1-1/2	4000	5 MICRON ABS
FH-106	PRESS DIFF. SWITCH	CUSTOM COMP. SWITCH	62DZEM2	1/4	3000	SET @ 25 PSID INCREASING
FH-107	PRESS X-DUCER			1/4	3500	CURE U3G, RANGE 0-2500 PSIG
FH-108	PRESS. REG.	GROVE	MODEL94	1/4	3500	CV-.6, CURE, DUAL BELLOWS CONSTRUCTION FIG. NO. 11485P2G
FH-109	PRESS REG.	GROVE	MODEL94	1/4	3500	CV=.6, CURE, DUAL BELLOWS CONSTRUCTION FIG. NO. 11485P2G
FH-110	RELIEF VALVE	CROSBY	463-125	1 IN 1-1/2 OUT	2500	TEFLON SEAL SET @ 185 PSIG
FH-111-A	BALL VALVE	WORCESTER	1/4-416-TSE	1/4	1000	CV=8
FH-111-B	ACTUATOR	WORCESTER	B35SN	1/4	100	F.O. W/TWO (2) DPDT LIMIT SWITCHES 5930-00-883-1533
FH-112	PSESS. SWITCH	UNITED ELECTRIC	J110A-270	1/4	250	SET @ 175 PSIG
FH-113	PRESS. SWITCH	UNITED ELECTRIC	J110A-270	1/4	250	SET @ 50 PSIG
FH-114	THERMOCOUPLE			1/4	3000	"K" CHROMEL/ALUMEL

TABLE III. - Continued

ITEM NO.	DESCRIPTION	MFGR.	MODEL	SIZE	W.P. PSIG	REMARKS AND/OR NASA STOCK NO.	
FH-115	PRESS. X-DUCER			1/4	2500	CURE U3G, RANGE 0-200 PSIA	
FH-116	VENTURI	FLOW DYNE	V080200	1/2	500	THROAT DIA.=.200 IN. S.S. BODY 1/8" 37 DEG. TUBE FITTINGS ON THROAT POR	
FH-117	PRESS. DIFF. X-DUCER			1/4	2000	CURE U4E RANGE 0-25 PSID	
FH-118-A	BALL VALVE	WORCESTER	1/2-416-TSE	1/2	1000		
FH-118-B	ACTUATOR	WORCESTER	B38SN	1/4	100	F.O. W/TWO (2) DPDT LIMIT SWITCHES 5930-00-883-1533	
FH-119	GLOBE VALVE	ANNIN	1660	1/2	1200	CV=1.0 PERCENTAGE; CURE	
FH-122-A	BALL VALVE	WORCESTER	1/2-416-TSE	1/2	1000	CV=8.0	
FH-122-B	ACTUATOR	WORCESTER	B38SN	1/4	100	F.C. W/TWO (2) DPDT LIMIT SWITCHES 5930-00-883-1533	
FH-123	GLOBE VALVE			1/4	3000	4820-00-554-9967	
FH-124	SOLENIOD VA.	ATKOMATIC	15400	1/4	300	CV=1.4	
FH-125	GLOBE VALVE	HOKE	2355F4Y	1/4	3000	CV=.30 MOTOR OPER.; OPER # 0121F2E	
FH-126	GLOBE VALVE	HOKE	2355F4Y	1/4	3000	CV=.30 MOTOR OPER.; OPER # 0121F2E	
FH-127	GLOBE VALVE	HOKE	2355F4Y	1/4	3000	CV=.30 MOTOR OPER.; OPER # 0121F2E	
FH-128	GLOBE VALVE	HOKE	2355F4Y	1/4	3000	CV=.30 MOTOR OPER.; OPER # 0121F2E	
FH-129	GLOBE VALVE	HOKE	2355F4Y	1/4	3000	CV=.30 MOTOR OPER.; OPER # 0121F2E	
FH-130	GLOBE VALVE	HOKE	2355F4Y	1/4	3000	CV=.30 MOTOR OPER.; OPER # 0121F2E	
FH-131	GLOBE VALVE	HOKE	2355F4Y	1/4	3000	CV=.30 MOTOR OPER.; OPER # 0121F2E	
FH-132	GLOBE VALVE	HOKE	2355F4Y	1/4	3000	CV=.30 MOTOR OPER.; OPER # 0121F2E	
FH-133	CHECK VALVE	NUPRO	SS-4C-10	1/4	3000	CV=.47; 1/4" SWAGELOK	
FH-134	CHECK VALVE	NUPRO	SS-4C-10	1/4	3000	CV=.47; 1/4" SWAGELOK	

TABLE III. - Continued

ITEM NO.	DESCRIPTION	MFGR.	MODEL	SIZE	W.P. PSIG	REMARKS AND/OR NASA STOCK NO.	
FH-135	CHECK VALVE	NUPRO	SS-4C-10	1/4	3000	CV=.47; 1/4" SWAGELOK	
FH-136	CHECK VALVE	NUPRO	SS-4C-10	1/4	3000	CV=.47; 1/4" SWAGELOK	
FH-137	CHECK VALVE	NUPRO	SS-4C-10	1/4	3000	CV=.47; 1/4" SWAGELOK	
FH-138	CHECK VALVE	NUPRO	SS-4C-10	1/4	3000	CV=.47; 1/4" SWAGELOK	
FH-139	CHECK VALVE	NUPRO	SS-4C-10	1/4	3000	CV=.47; 1/4" SWAGELOK	
FH-140	CHECK VALVE	NUPRO	SS-4C-10	1/4	3000	CV=.47; 1/4" SWAGELOK	
FH-141	SOLENIOD VA.	ATKOMATIC	15400	1/4	300	CV=1.4	
FH-142	SOLENIOD VA.	ATKOMATIC	15400	1/4	300	CV=1.4	
FH-143	SOLENIOD VA.	ATKOMATIC	15400	1/4	300	CV=1.4	
FH-144	SOLENIOD VA.	ATKOMATIC	15400	1/4	300	CV=1.4	
FH-145	SOLENIOD VA.	ATKOMATIC	15400	1/4	300	CV=1.4	
FH-146	SOLENIOD VA.	ATKOMATIC	15400	1/4	300	CV=1.4	
FH-147	SOLENIOD VA.	ATKOMATIC	15400	1/4	300	CV=1.4	
FH-148	SOLENIOD VA.	ATKOMATIC	15400	1/4	300	CV=1.4	
FH-149	CHECK VALVE	NUPRO	SS-4C-10	1/4	3000	CV=.47; 1/4" SWAGELOK	
FH-150	CHECK VALVE	NUPRO	SS-4C-10	1/4	3000	CV=.47; 1/4" SWAGELOK	
FH-151	CHECK VALVE	NUPRO	SS-4C-10	1/4	3000	CV=.47; 1/4" SWAGELOK	
FH-152	CHECK VALVE	NUPRO	SS-4C-10	1/4	3000	CV=.47; 1/4" SWAGELOK	
FH-153	CHECK VALVE	NUPRO	SS-4C-10	1/4	3000	CV=.47; 1/4" SWAGELOK	
FH-154	CHECK VALVE	NUPRO	SS-4C-10	1/4	3000	CV=.47; 1/4" SWAGELOK	
FH-155	CHECK VALVE	NUPRO	SS-4C-10	1/4	3000	CV=.47; 1/4" SWAGELOK	
FH-156	CHECK VALVE	NUPRO	SS-4C-10	1/4	3000	CV=.47; 1/4" SWAGELOK	
FH-157	THERMOCOUPLE			1/4	3000	TYPE "K", CHROMEL/ALUMEL	
FH-158	THERMOCOUPLE			1/4	3000	TYPE "K", CHROMEL/ALUMEL	
FH-159	THERMOCOUPLE			1/4	3000	TYPE "K", CHROMEL/ALUMEL	
FH-160	THERMOCOUPLE			1/4	3000	TYPE "K", CHROMEL/ALUMEL	
FH-161	THERMOCOUPLE			1/4	3000	TYPE "K", CHROMEL/ALUMEL	
FH-162	THERMOCOUPLE			1/4	3000	TYPE "K", CHROMEL/ALUMEL	

TABLE III. - Continued

ITEM NO.	DESCRIPTION	MFGR.	MODEL	SIZE	W.P. PSIG	REMARKS AND/OR NASA STOCK NO.
FH-163	THERMOCOUPLE			1/4	3000	TYPE "K", CHROMEL/ALUMEL
FH-164	THERMOCOUPLE			1/4	3000	TYPE "K", CHROMEL/ALUMEL
FH-165	CHECK VALVE	NUPRO	SS-4C-10	1/4	3000	CV-.47; 1/4" SWAGELOK
FH-166-A	BALL VALVE	WORCESTER	1/2-416-TSE	1/4	1000	CV-8.0
FH-166-B	ACTUATOR	WORCESTER	B38SN	1/4	100	W/TWO (2) DPDT LIMIT SWITCHES 5930-00-883-1533
FH-167	CHECK VALVE	REPUBLIC	483-1-B-1	1	3000	CV=.3; CURE
FH-168-A	GAUGE	U.S. GAUGE		1/4	500	RANGE 0-500 PSIG
FH-168-B	GLOBE VALVE	HOKE	R380AK	1/4		
FH-169-A	GAUGE	U.S. GAUGE		1/4	500	RANGE 0-500 PSIG
FH-169-B	GLOBE VALVE	HOKE	R380AK	1/4		
N-201	PRESS X-DUCER			1/4	3000	CURE U3G; RANGE 0-2500 PSIG
N-202	GLOBE VALVE			1/4	3000	4820-00-879-5827
N-203	CYLINDER REG.	HARRIS CAL.	92-100-580		4000	CURE; INLET CGA-580 INLET 9/16-18 RH
N-204	RELIEF VALVE	REPUBLIC 3/8-M6	8-2366	3/8	3000	CURE; SET @ 75 PSIG
N-205	SOLENIOD VA.	ASCO	8320-A185	1/4	150	CV=.15
N-206	FLEXHOSE					NASA ASSY
N-208	PRESS. SWITCH	UNITED ELECTRIC	J302-610	1/4	10,000	SET@ 200 PSIG, DECREASING RANGE 100-1000 PSIG
N-209	CYLINDER REG.	HARRIS CALORIFIC	93-250-580		4000	CURE; SET @ 150 PSIG RANGE 0-250 PSIG
N-210	RELIEF VALVE	REPUBLIC	637B-3-3/4-TU5	3/4	3000	CURE; SET @ 175 PSIG
N-211	CHECK VALVE			1	3000	CV-13; 4820-00-529-4384
N-212	BALL VALVE	JAMESBURY	1/2-B36GT	1/2	3000	CV-8.0 W/LOCKING HANDLE
N-213	CYLINDER REG.	HARRIS CALORIFIC	93-350-580		4000	CURE; INLET CGA580 OUTLET 9/16-18RH
N-214	LOADER	TESCOM	26-1623-24	1/4	6000	CURE; CV=.08 RELIEVING RANGE 0-500 PSI

TABLE III. - Continued

ITEM NO.	DESCRIPTION	MFGR.	MODEL	SIZE	W.P. PSIG	REMARKS AND/OR NASA STOCK NO.
N-215	PRESS GAUGE			1/4	600	6685-00-295-6362 RANGE 0-600 PSI
N-216	RELIEF VALVE	REPUBLIC	637B-3-3/8-TF4	3/8	3000	CURE; SET@ 375 PSIG
N-217	LOADER	TESCOM		1/4	6000	CURE; CV=.08 RELIEVING RANGE 0-500 PSI
N-218	PRESS GAUGE			1/4	400	6685-00-295-6361 RANGE 0-400 PSIG
N-219	RELIEF VALVE	REPUBLIC	637B-2-3/8-2B2	3/8	3000	CURE; SET @ 200PSIG
N-220	PRESS SWITCH	UNITED ELECTRIC	J302-610	1/4	3000	SET @ 200 PSIG DECREASING
N-221	CYLINDER REG.	HARRIS CALORIFIC	93-250-580		4000	CURE; SET @ 100 PSIG RANGE 0-250 PSIG
N-222	SOLENIOD VA.	ATKOMATIC	15400	1/4	300	CV-1.4
N-223	RELIEF VALVE	REPUBLIC	637B	3/4	3000	CURE; SET@ 125 PSIG
N-224	SOLENIOD VA.	ATKOMATIC	15400	1/4	300	CV=1.4
N-225	PRESS REG.	CONOFLOW	H10	1/4	125	4280-00=540-6067 W/H117 SPRING RANGE 0-5 PSIG
N-226	RELIEF VALVE	REPUBLIC	637B	3/8	3000	CURE; SET@ 4PSIG
N-227	PRESS GAUGE			1/4	15	6685-00-295-6365 RANGE 0-15 PSIG
N-228	PRESS DIFF. SWITCH	DWYER	1823-20	1/8	10	SPDT; SET@ .5 PSID DECREASING
N-229	SOLENIOD VA.	HANNIFIN	4-WAY	1/4	150	CURE
N-230	SOLENIOD VA.	HANNIFIN	4-WAY	1/4	150	CURE
N-231	SOLENIOD VA.	ATKOMATIC	15400	1/4	300	CV=1.4
N-232	SOLENIOD VA.	ATKOMATIC	15400	1/4	300	CV=1.4
N-233	SOLENIOD VA.	ATKOMATIC	15400	1/4	300	CV=1.4
N-234	SOLENIOD VA.	ATKOMATIC	15400	1/4	300	CV=1.4
N-235	SOLENIOD VA.	ATKOMATIC	15400	1/4	300	CV=1.4
N-236	SOLENIOD VA.	ATKOMATIC	15400	1/4	300	CV=1.4

TABLE III. - Concluded

ITEM NO.	DESCRIPTION	MFGR.	MODEL	SIZE	W.P. PSIG	REMARKS AND/OR NASA STOCK NO.
N-237	SOLENIOD VA.	ATKOMATIC	15400	1/4	300	CV=1.4
N-238	SOLENIOD VA.	ATKOMATIC	15400	1/4	300	CV=1.4
AI-301	LOADER			1/4	150	4820-00-540-6067 RANGE 0-15 PSIG
AI-302	PRESS GAUGE			1/4	30	6685-00-295-6354 RANGE 0-30 PSIG
AS-402	SOLENOID VA.	HANNIFIN	4-WAY	1/4	150	CURE
AS-403	SOLENOID VA.	HANNIFIN	4-WAY	1/4	150	CURE

TABLE IV. - TIME CONSTANT CALIBRATION RESULTS

[Stream static pressure, p, 14.41 psia.]

Stream Mach number	Probe indicated temperature, T_i, °F	Measured time constant, τ, sec	Reference time constant, τ_0, sec
0.40	160	0.222	0.127
.30	147	.253	.126
.20	156	.300	.122
.15	160	.365	.128
.10	156	.490	.141
0	170	1.05	0

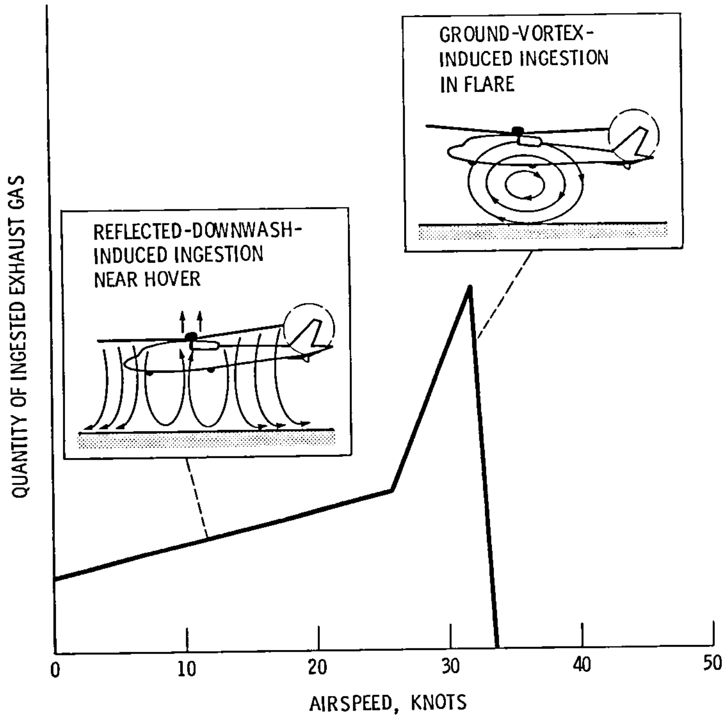


Figure 1. - Patterns of exhaust ingestions near ground.

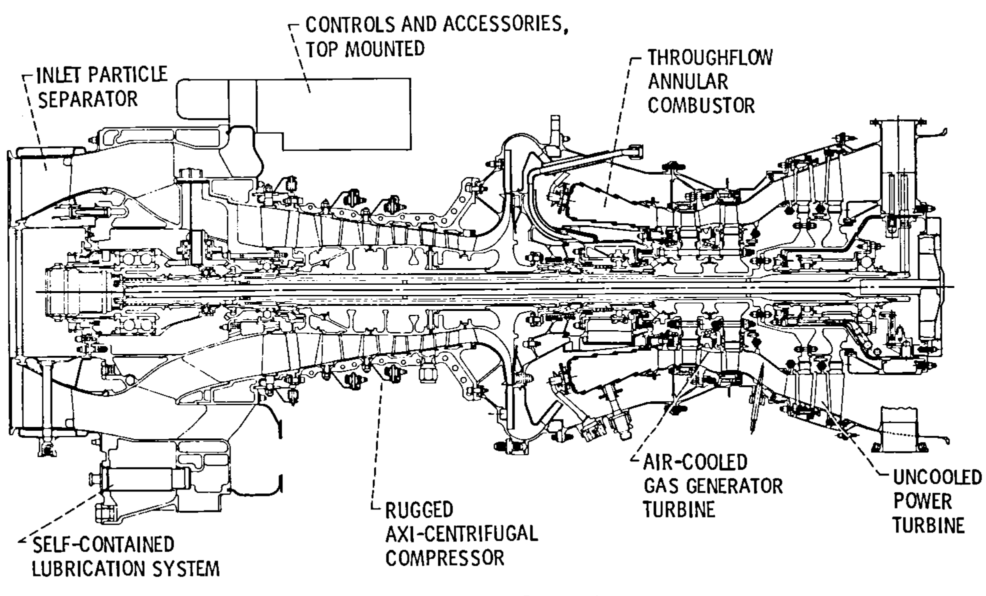


Figure 2. - Schematic of T700 engine.

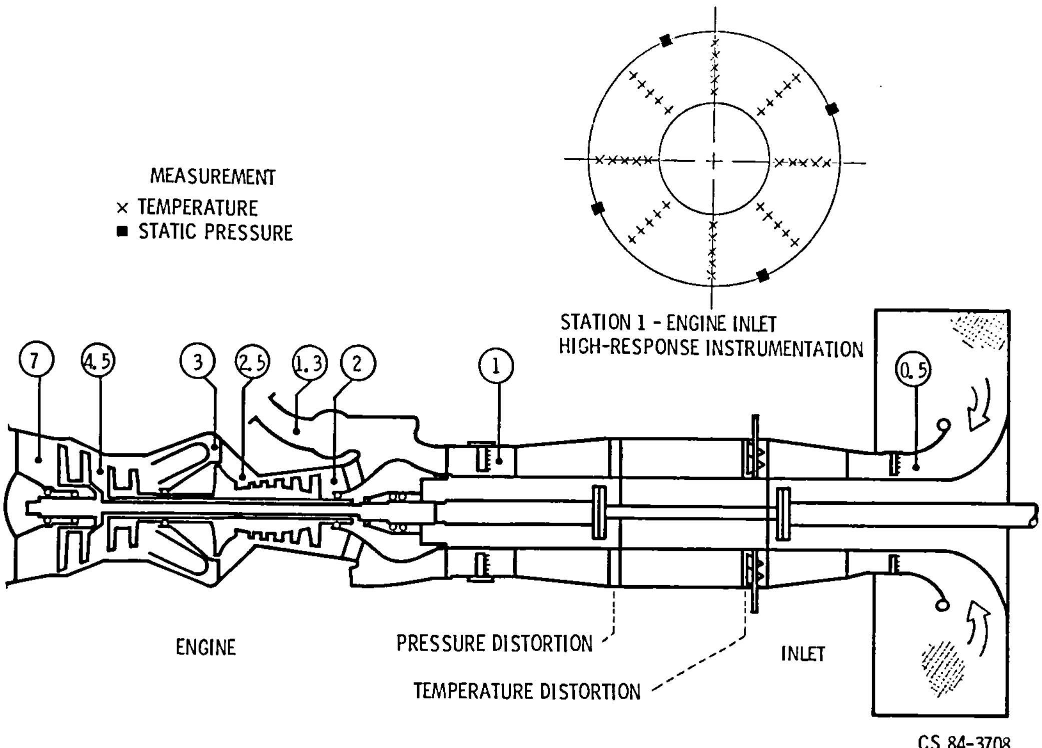
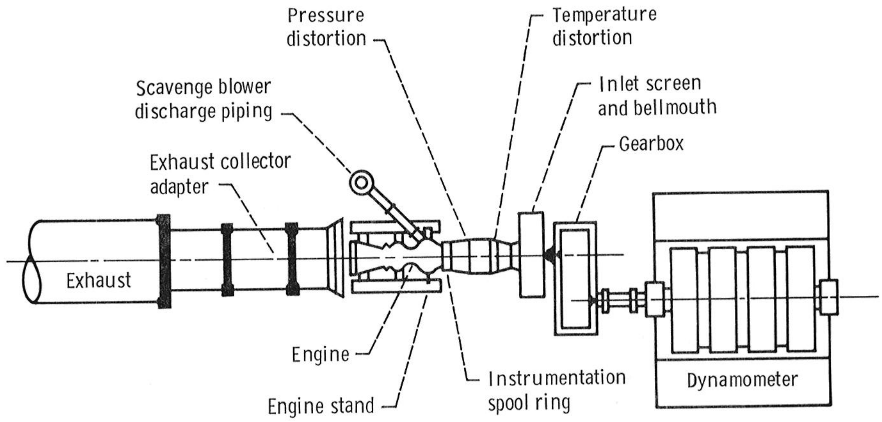
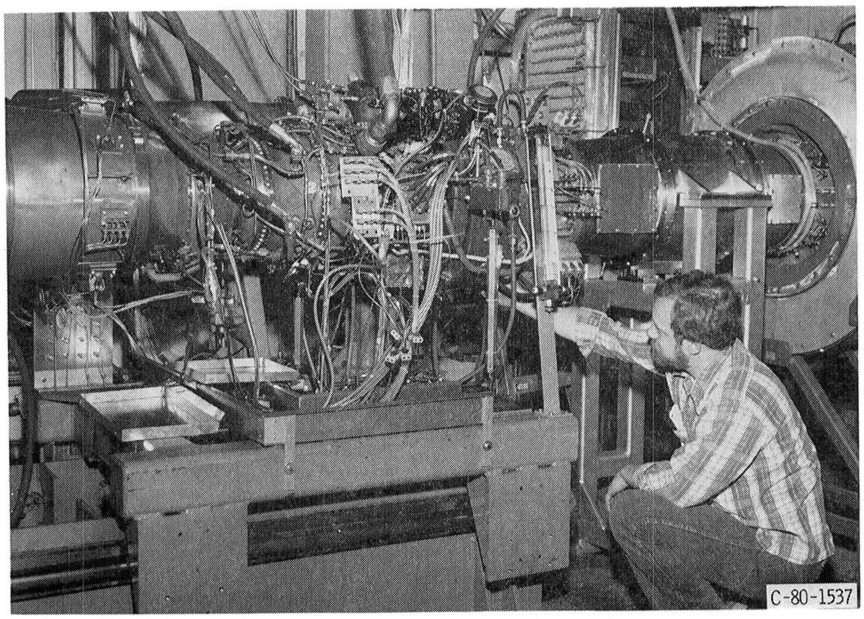


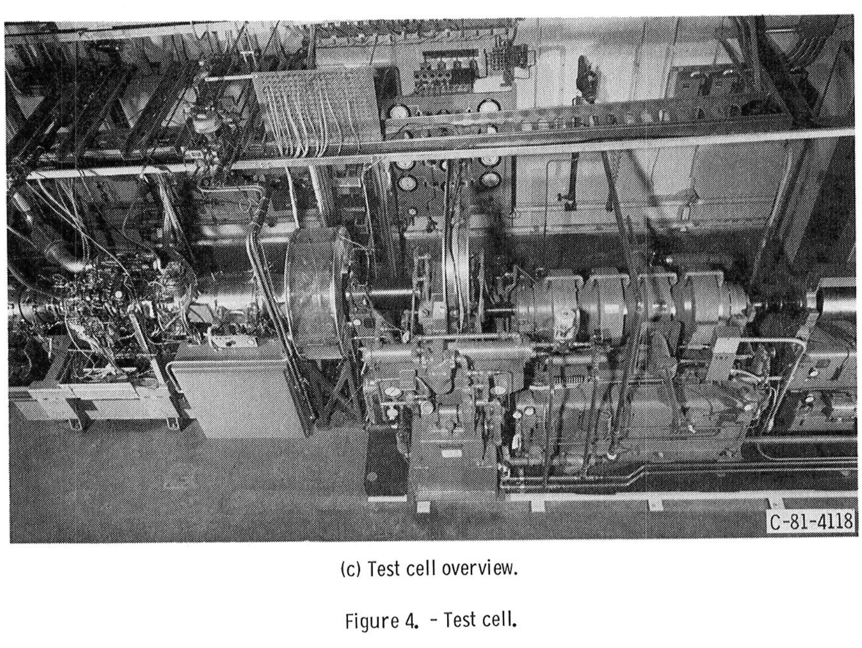
Figure 3. - Instrumentation station locations.



(a) Plan view (not to scale).

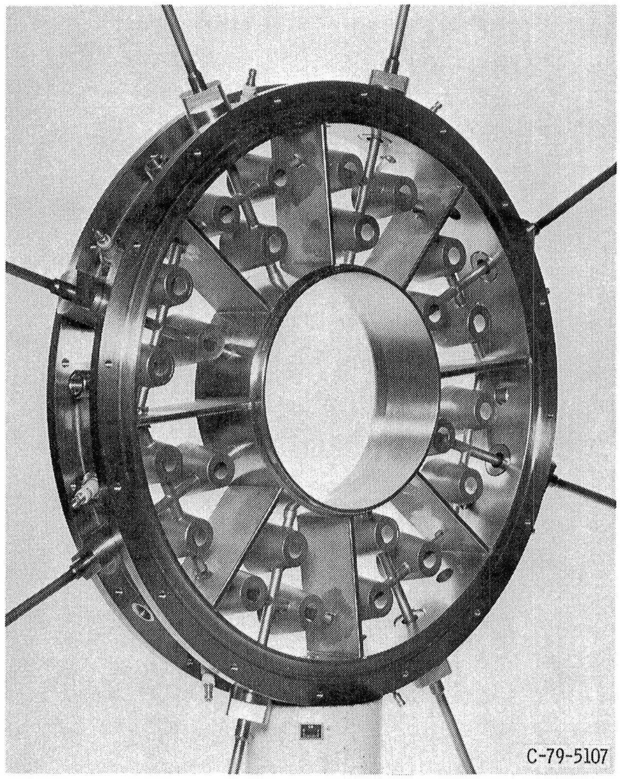


(b) Engine installation.

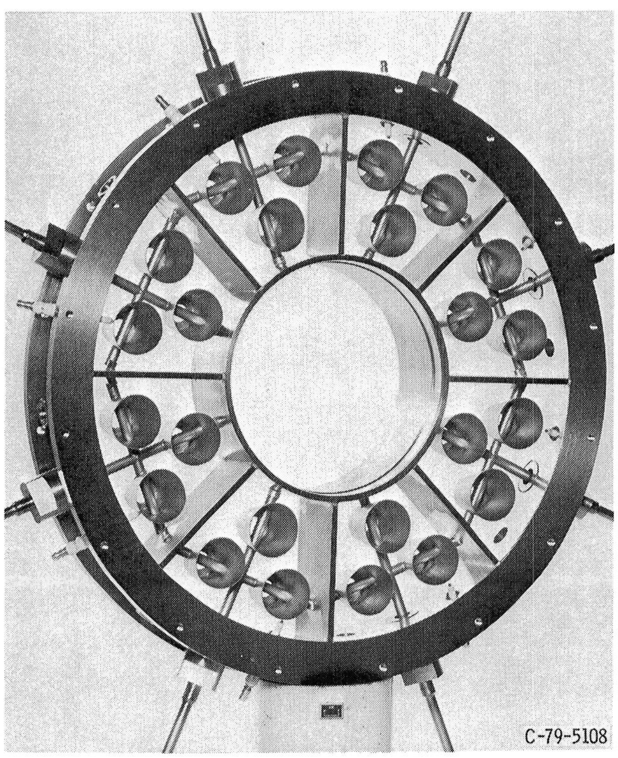


(c) Test cell overview.

Figure 4. - Test cell.



(a) Looking downstream.



(b) Looking upstream.

Figure 5. - Temperature distortion generator.

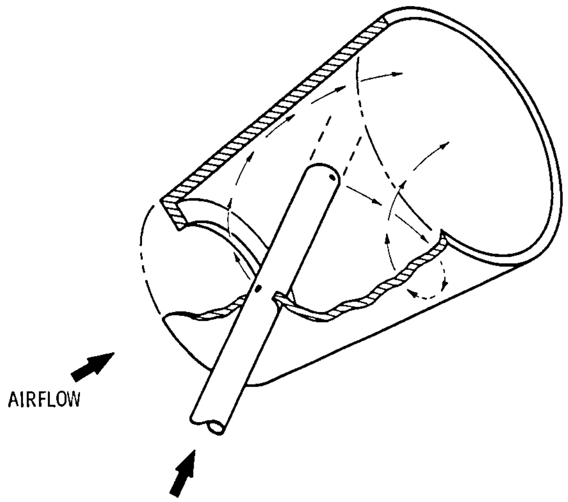
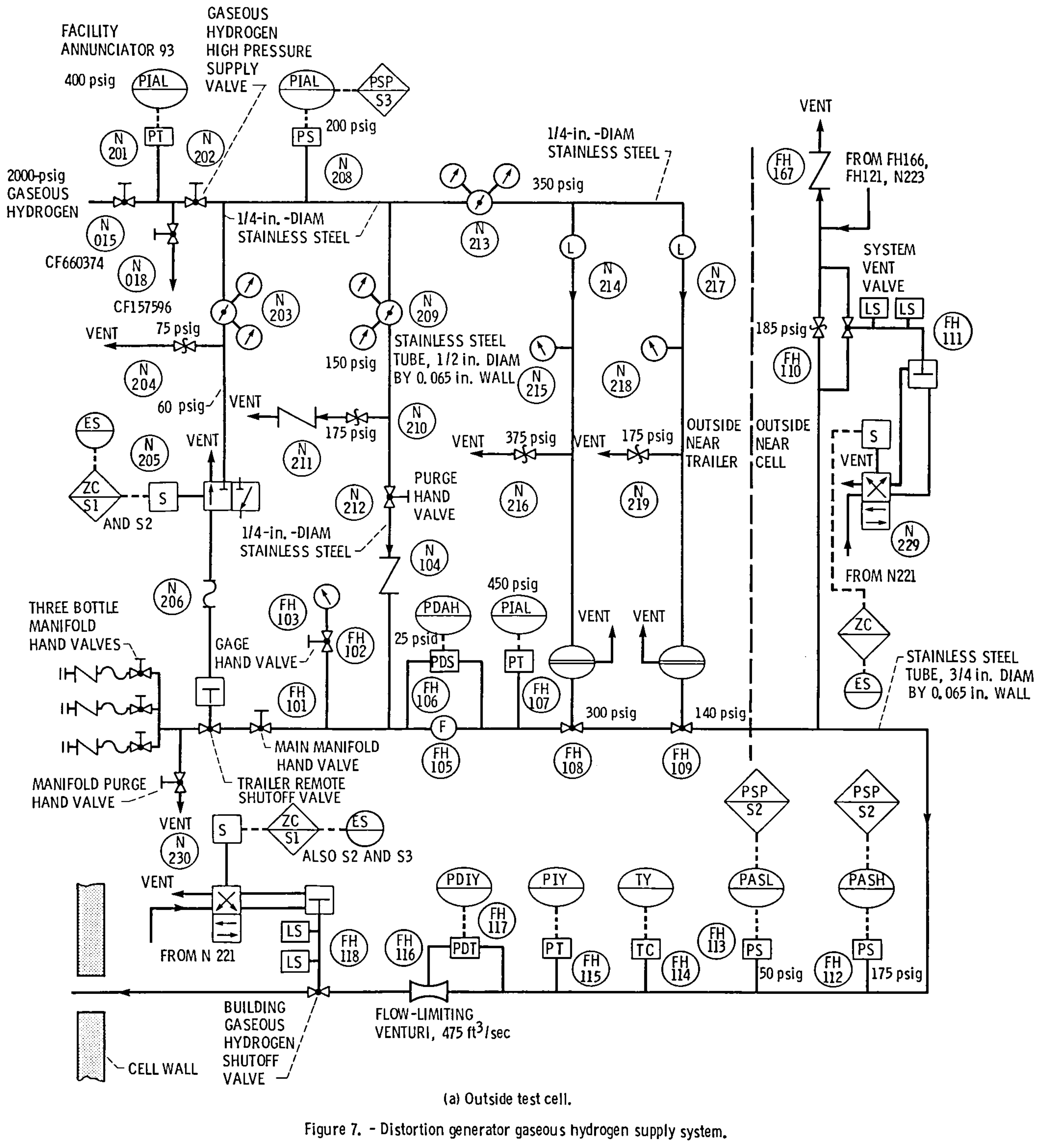
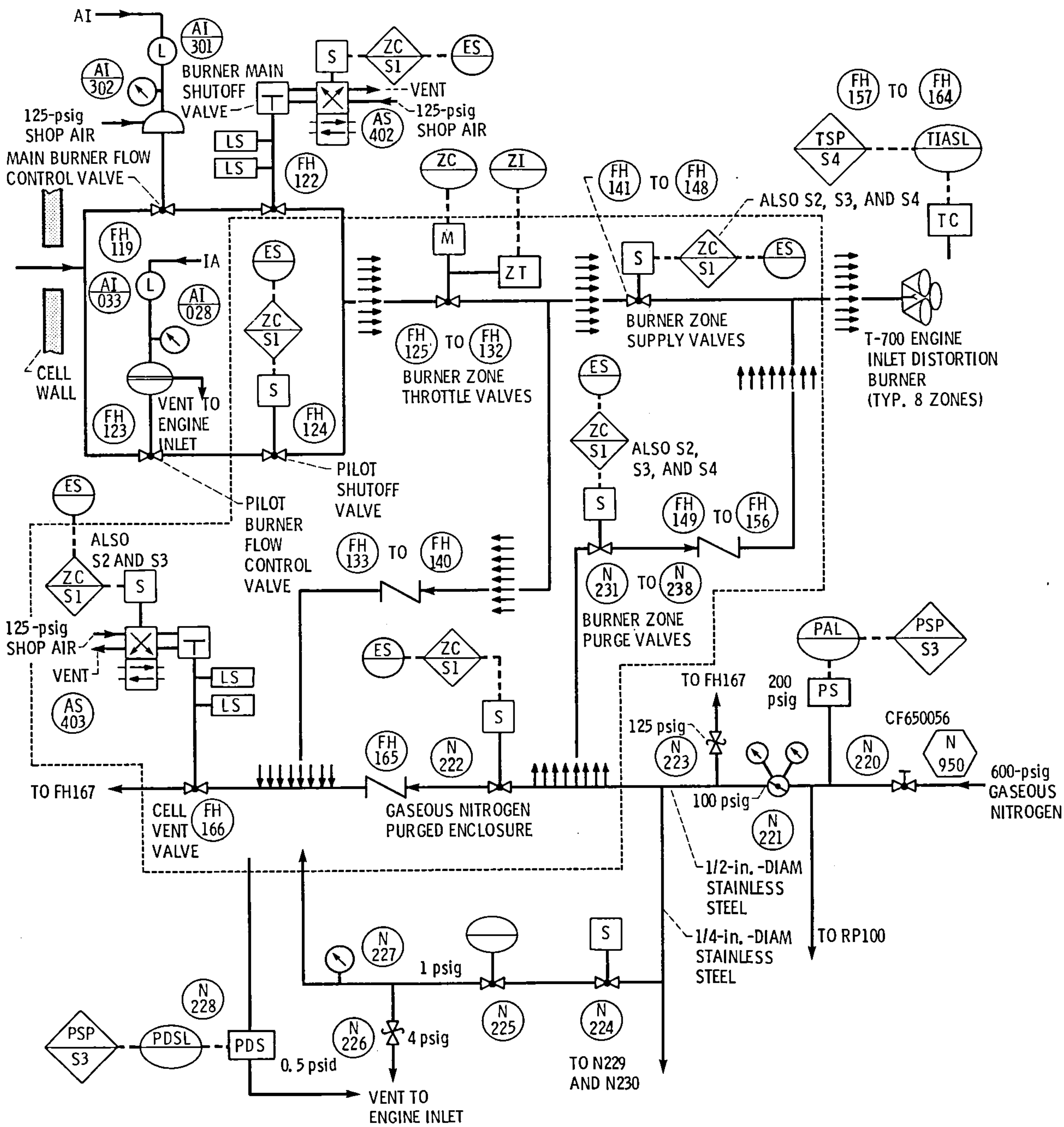


Figure 6. - Operation of typical swirl-cup combustor.



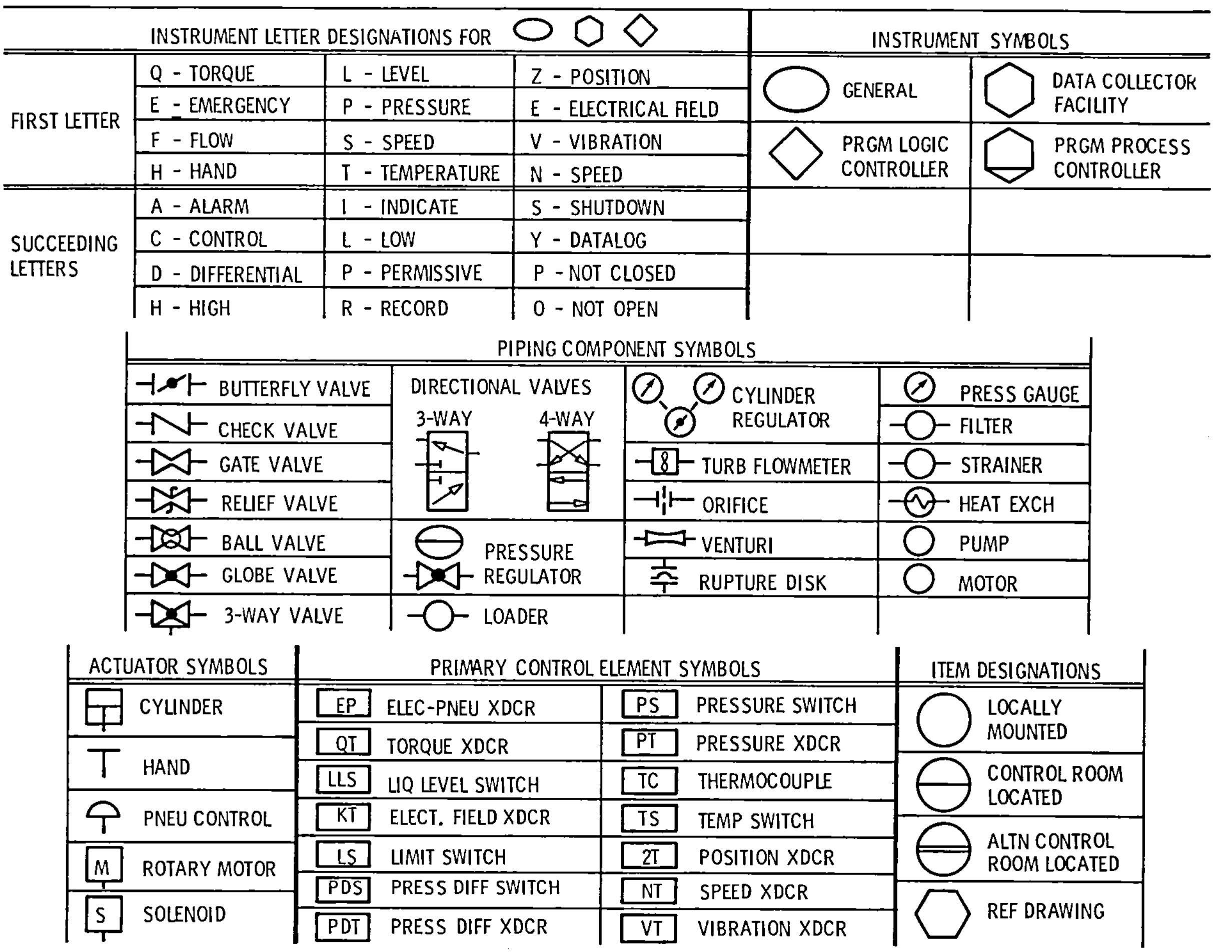
(a) Outside test cell.

Figure 7. - Distortion generator gaseous hydrogen supply system.



(b) Inside test cell.

Figure 7. - Continued.



(c) Legend.

Figure 7. - Concluded.

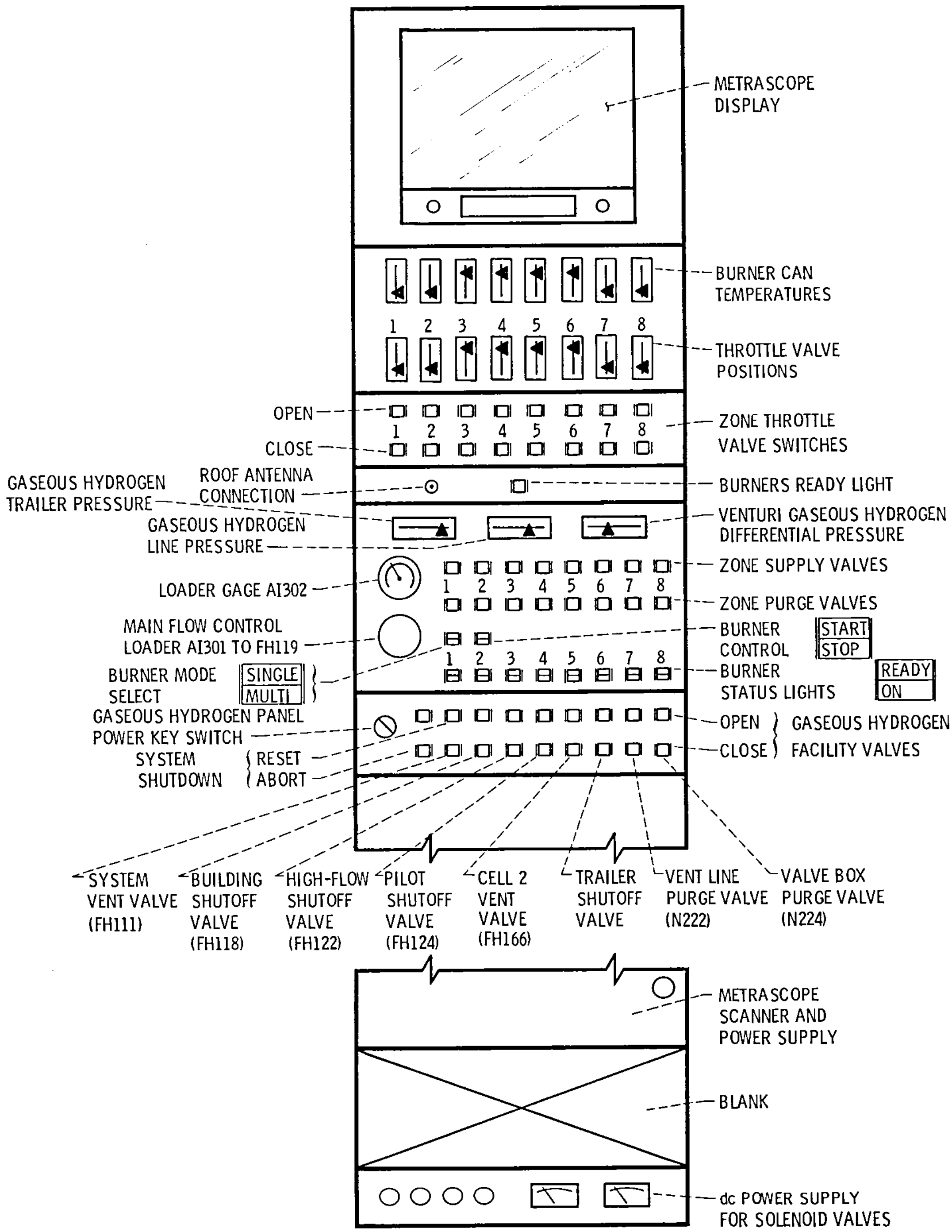


Figure 8. - Hydrogen system control panel. Pilot flow control loader AI033 to FH123 and gage AI028 are in cabinet 13.

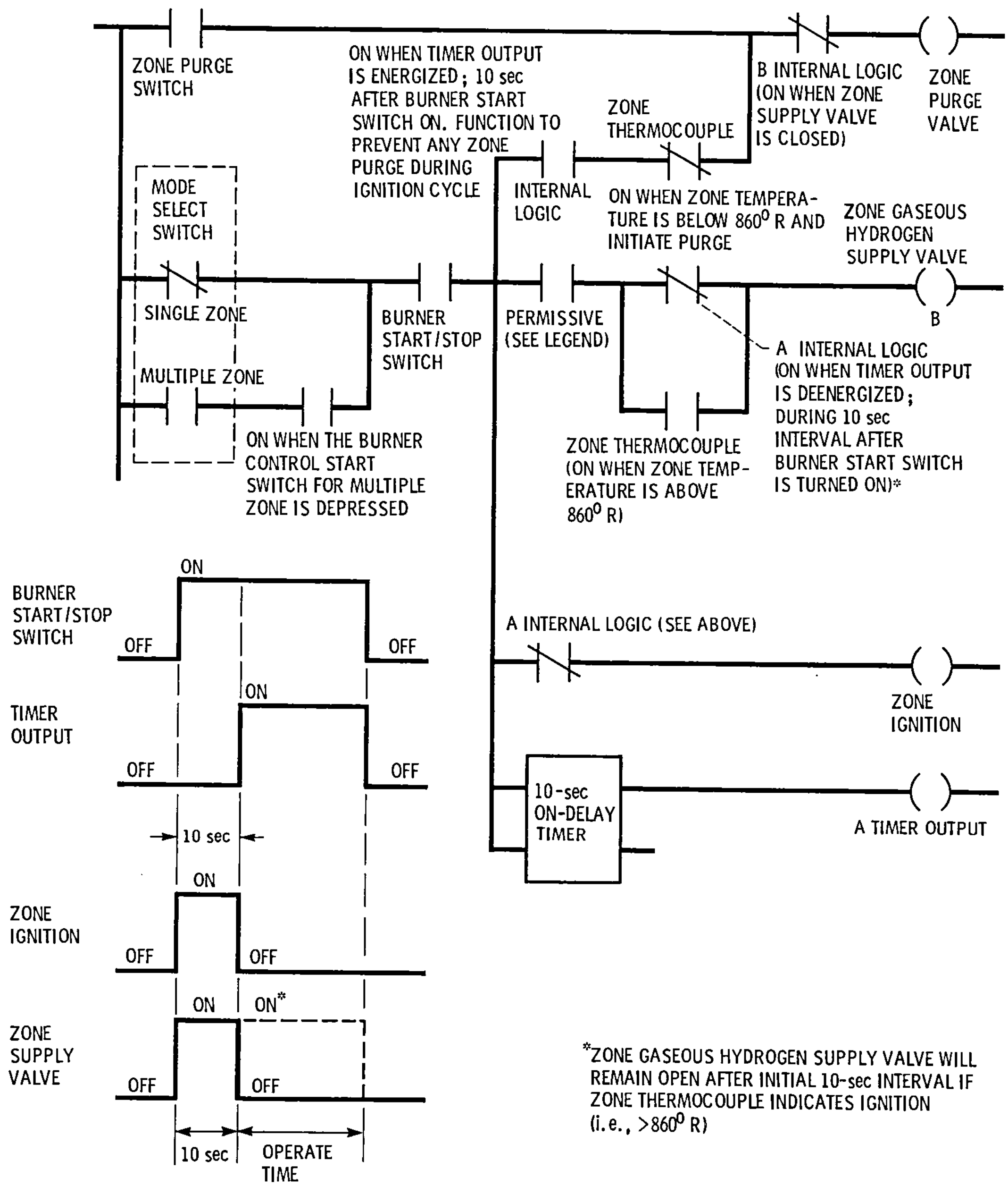


Figure 9. - Control logic for hydrogen system burner zones. Permissive is satisfied when (1) system on/off panel switch is on; (2) system reset switch is depressed; (3) engine is at or above idle speed; (4) valve box purge pressure is > 0.5 psid; (5) gaseous hydrogen line pressure is > 50 psig; (6) burner gaseous nitrogen purge pressure is > 200 psig; (7) gaseous hydrogen line pressure is < 175 psig; (8) facility gaseous nitrogen purge pressure is > 400 psig; and (9) gaseous hydrogen key switch is on.

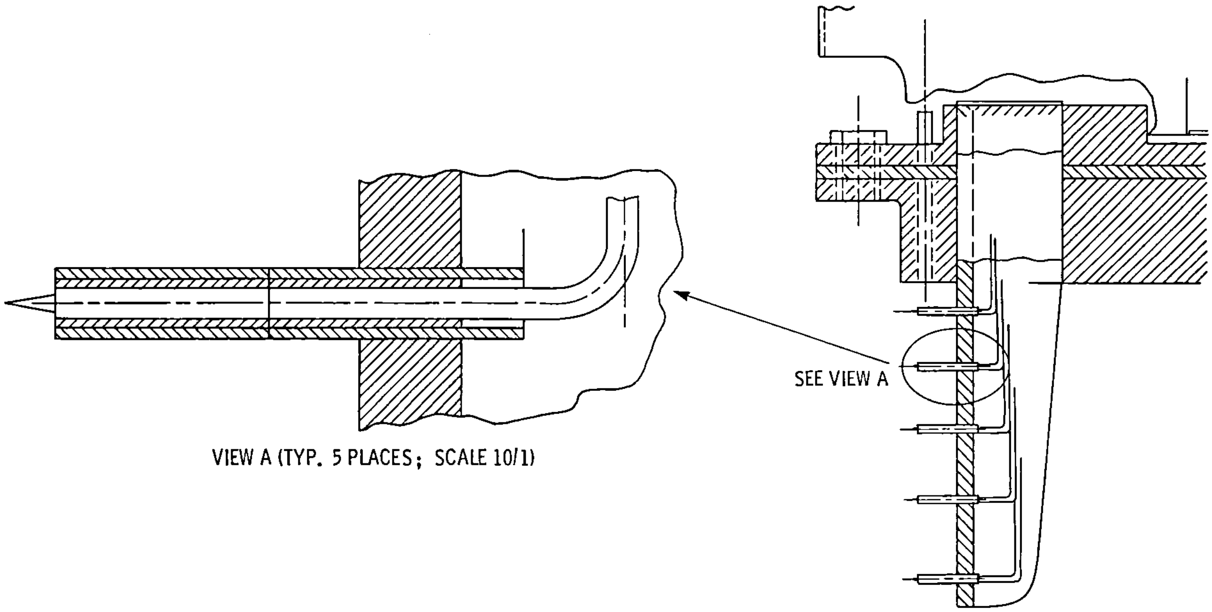


Figure 10. - Chromel-Alumel thermocouple probe.

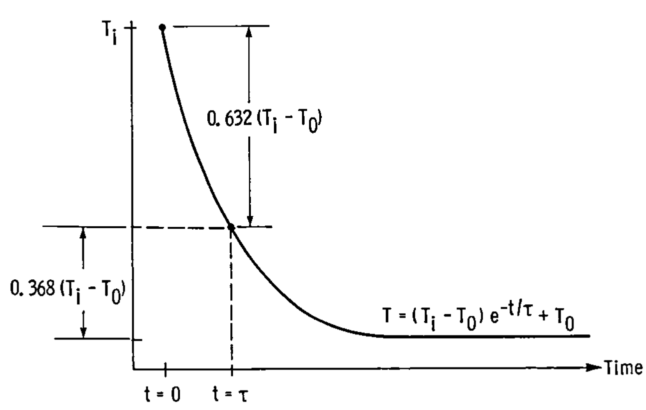


Figure 11. - Exponential decay curve.

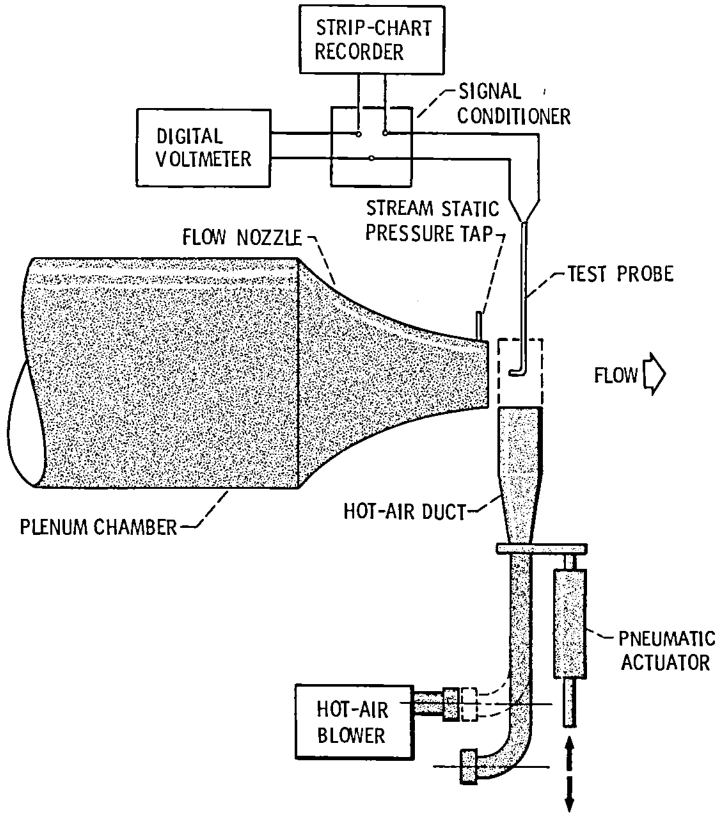


Figure 12. - Time-constant test apparatus.

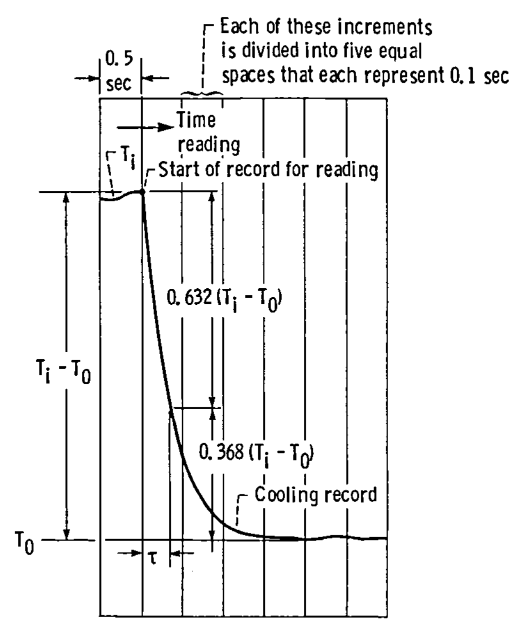


Figure 13. - Sample record.

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4. Title and Subtitle Temperature Distortion Generator for Turboshaft Engine Testing		5. Report Date
		6. Performing Organization Code 505-32-6A
7. Author(s) Gary A. Klann, Richard L. Barth, and Thomas J. Biesiadny		8. Performing Organization Report No. E-2197
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9. Performing Organization Name and Address NASA Lewis Research Center and Propulsion Laboratory U.S. Army Research and Technology Laboratories (AVSCOM) Cleveland, Ohio 44135		11. Contract or Grant No.
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15. Supplementary Notes

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16. Abstract

The procedures and unique hardware used to conduct an experimental investigation into the response of a small-turboshaft-engine compression system to various hot gas ingestion patterns are presented. The temperature distortion generator described herein uses gaseous hydrogen to create both steady-state and time-variant, or transient, temperature distortion at the engine inlet. The range of transient temperature ramps produced by the distortion generator during the engine tests was from less than 111 deg K/sec (200 deg R/sec) to above 611 deg K/sec (1100 deg R/sec); instantaneous temperatures to 422 deg K (760 deg R) above ambient were generated. The distortion generator was used to document the maximum inlet temperatures and temperature rise rates that the compression system could tolerate before the onset of stall for various circumferential distortions as well as the compressor system response during stall.

17. Key Words (Suggested by Author(s)) Engine tests; Ground tests; Burners; Ingestion (engines); Temperature distortion; Aerodynamic stalling; Transients (surges)	18. Distribution Statement Unclassified - unlimited STAR Category 01

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