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16. Abstract

A cryogenic H_2-O_2 APU was developed and successfully demonstrated. It has potential application as a minimum weight alternate to the Space Shuttle baseline APU because of its (1) low specific propellant consumption and (2) heat sink capabilities that reduce the amount of expendable evaporants. A reference system was designed with the necessary heat exchangers, combustor, turbine-gearbox, valves and electronic controls to provide 400 shp to two aircraft hydraulic pumps.

Development testing was carried out first on the combustor and control valves. This was followed by development of the control subsystem including the controller, the hydrogen and oxygen control valves, the combustor, and a turbine simulator. The complete APU system was hot tested for 10 hr with ambient and cryogenic propellants. Demonstrated SPC at 95 percent of design power was 2.25 lb/hp-hr. At 10 percent design power, specific propellant consumption was 4 lb/hp-hr with space simulated exhaust and 5.2 lb/hp-hr with ambient exhaust. A 10 percent specific propellant consumption improvement is possible with some seal modifications. It was demonstrated also that APU power levels could be changed by several hundred horsepower in less than 100 msec without exceeding allowable turbine inlet temperatures or turbine speed.

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FOREWORD

The H_2-O_2 Space Shuttle auxiliary power unit (APU) program is a NASA-Lewis effort aimed at hardware demonstration of the technology required for potential use on the Space Shuttle. This program was conducted under the direction of Harry M. Cameron, Project Manager, NASA-Lewis Research Center. It was a follow-on effort to two study programs conducted under Contracts NAS 3-14407 and NAS 3-14408. The results of these studies were reported in the following NASA Contractor Reports: NASA CR-2001, -1994, -1995, -1996, -1997, -1993, and 1928. Design activity under this program was reported in NASA Contractor Report CR-121214.

The requirements of NASA Policy Directive NPD 2220.4 (14 September 1970) regarding the use of SI units have been waived in accordance with the provisions of para. 5d of that directive by the Director of Lewis Research Center.

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SUMMARY

An H_2-O_2 auxiliary power unit (APU) was designed and developed to meet NASA specifications for an alternate Space Shuttle APU. The program objectives were to develop the technology for the design of an H_2-O_2 APU which would have low specific propellant consumption and be capable of utilizing the cryogenic propellants as a heat sink for the APU and the hydraulic system. The development passed through a logical sequence of analysis, design, fabrication, test, and updating of the computer simulator model. The program objectives were met with an APU reference system that incorporated necessary propellant conditioning valves and heat exchangers, combustor, turbine and gearbox assembly, and electronic propellant flow control system providing 400-shp output to two hydraulic pumps. The experimental test APU (APU-T) that incorporated all significant flight APU features demonstrated the viability of a hydrogen-oxygen APU. The test unit accumulated approximately 10 hr test time with 145 hot starts. Extrapolations of performance at 350 to 380 hp demonstrated a specific propellant consumption (SPC) of about 2.2 at 400 hp under space simulation.

The APU-T system was a close-coupled experimental test version of a reference system designed in the program; it was schematically the same, but was altered to reduce development costs. Flight-type components were used, except for the gearbox. Also, a nitrogen buffer labyrinth seal replaced the reference system turbine face seal; an external lubrication system, functioning after shutdown, obviated heat soakback protection; and the recuperator was designed for ground tests where internal pressure was vacuum and external pressure was ambient.

Development problems were solved during component, subsystem, and system tests. The main problem that occurred in system tests that did not occur in component or subsystem tests was spark plug melting. It was encountered only when the turbine was installed in the system tests. The problem was eliminated, but reoccurred near the end of the test program. The test program was terminated before the solution to the plug melting problem could be demonstrated.

Component and system performance compared favorably with predictions. The combustor provided near 100-percent efficiency and stable combustion over the range of test chamber pressures. It had the ability to operate over a wide range of O/F ratios and chamber pressures. The turbine efficiency was about 44 to 48 percent or about 4 to 8 points lower than expected, probably because of excessive honeycomb seal leakage. Using smaller cells in the honeycomb would reduce this leakage. The cooling capability of 400 hp for the hydraulic system was about 4700 Btu/min. Turbine speed was controlled within 1 percent of the mean during steady-state and transient operation. During 100-hp load steps, the turbine inlet temperature was controlled within 40 R. No temperature spikes or overspeed conditions occurred during startup and shutdown. The proper propellant conditioning was obtained with hydrogen inlet temperature to the combustor controlled within 15 R and hydrogen inlet temperature to the hydraulic oil cooler controlled within 10 R.

A computer simulator was developed to verify the effects of control options and control parameters, and the effects of system configuration changes on transient APU performance. The simulator is operational on the NASA-LRC computer and may be utilized to make future changes, including power scaling.

INTRODUCTION

Two study programs performed for the NASA Lewis Research Center under Contracts NAS 3-14407 and NAS 3-14408 showed a hydrogen-oxygen auxiliary power unit (APU) system to be an attractive alternate to the Space Shuttle baseline hydrazine APU system for minimum weight. In addition to providing a low specific propellant consumption relative to hydrazine, an APU system using cryogenic hydrogen has the capability to meet many of the heat sink requirements for the Space Shuttle vehicle, thereby greatly reducing the amount of water or other expendable evaporant that must be provided with the baseline APU for cooling.

AiResearch was awarded Contract NAS 3-15708 in April 1972 to design, build, and test a cryogenic hydrogen-oxygen fueled 400-hp APU suitable for the Space Shuttle orbiter. The primary objective of the program was to demonstrate the APU technology required for a long-life, reusable, hydraulic and electric APU. The initial APU system configuration, which was based on work done in the previous studies, incorporated a recycle loop driven by a jet pump to maximize the amount of available cooling, and several heat exchanger bypass loops for propellant conditioning. A steady-state digital computer program was formulated and a large matrix of flight conditions, power settings, and design variables was examined. These design studies showed performance prediction uncertainties associated with the jet pump operation over a wide range of conditions. Then a new reference system was studied in which the jet pump was replaced by a new heat exchanger called the regenerator, which also maximized the amount of available cooling.

An APU flight-type reference system was designed to meet NASA specifications and contained necessary propellant conditioning valves and heat exchangers, combustor, turbine and gearbox assembly, and an advanced design, electronic propellant flow control system to provide 400-shp output to two hydraulic pumps. A design report, ref. 1, covers the design requirements and the solution to meet those requirements.

A test system also was designed to be a close-coupled experimental test version of the reference system. Designated the APU-T, it incorporated all significant reference system design features as well as additional options to be investigated and included instrumentation to allow investigation and development of the technology required to develop a flight-qualified APU design. Many components were flight-type, which had appropriate dynamic characteristics and received sufficient evaluation to provide reasonable assurance of being qualified for flight application with some modification. The test system assembly was packaged with emphasis on accessibility. Special features were added to the control for turbine calibration and system development. In addition, some cost-saving modifications that would not affect the technical objectives were made.

This report covers the final reference system design, but is principally concerned with the test results of the APU-T system that was tested both at ambient pressure and space simulation.

REFERENCE SYSTEM

Reference System Description

The reference system (see fig. 1) consists of a propellant feed and conditioning subsystem, turbopower subsystem, and control subsystem. The propellant feed and conditioning subsystem begins at the outlet of the high-pressure propellant tanks and contains all heat exchangers and the combustor. The turbopower subsystem contains a two-stage partial-admission pressure-modulated 430-hp turbine, a zero- to 4-g lubrication system, and a zero-g gearbox with multiple output pads to accommodate two hydraulic pumps and an alternator. The control subsystem contains the electronics required to control primary system functions as well as secondary functions incident to system operation and safety and the valves required for control.

The cold hydrogen is first heated in a hydrogen preheater by hydrogen from the recuperator. Secondly, it flows through a regenerator where it receives heat from the reentrant hydrogen flow that has been the sink for hydraulic pump case drain waste heat. Out of the regenerator both hydrogen streams are now between 400 and 460 R, controlled by the preheater bypass loop. One stream flows through the hydraulic cooler; the other through the lube cooler and the recuperator. The last pass is through the hydrogen-oxygen temperature equalizer where the oxygen is conditioned to be close to the hydrogen temperature. Except for the flow bypasses, one around the recuperator, the other around the preheater that act as flow dividers, the hydrogen describes a single path through the propellant conditioning system.

The preheater bypass loop flow is controlled to maintain the lube oil temperature below the maximum permissible operating temperature, but above the congealing temperature, and preferably in the range between 650 and 700 R. As shown on the temperature schedule (inset in fig. 1), when the lube oil temperature is 650 R, the hydrogen temperature out of the first preheater pass will be controlled by an appropriate preheater bypass flow rate to 460 R. As the lube oil temperature increases (usually at low power output), the hydrogen temperature will be controlled down to 400 R (but not lower, to avoid local congealing).

The preheater bypass loop flow increases with higher hydraulic and lube cooler heat loads. In those cases, most of the preheating will occur in the regenerator. The bypass flow also will increase with increasing hydrogen fluid temperatures. This is the case with a thermally pressurized supercritical tank supply.

The recuperator bypass loop flow is controlled by the hydrogen temperature downstream of the temperature equalizer, attempting to maintain 750 R combustor inlet. At high power levels, the engine operates more efficiently and insufficient heat is available in the recuperator to attain this temperature even at zero bypass. Computer simulation shows, however, that with 55 R hydrogen inlet and full power, combustor inlet temperature will be no lower than 680 R.

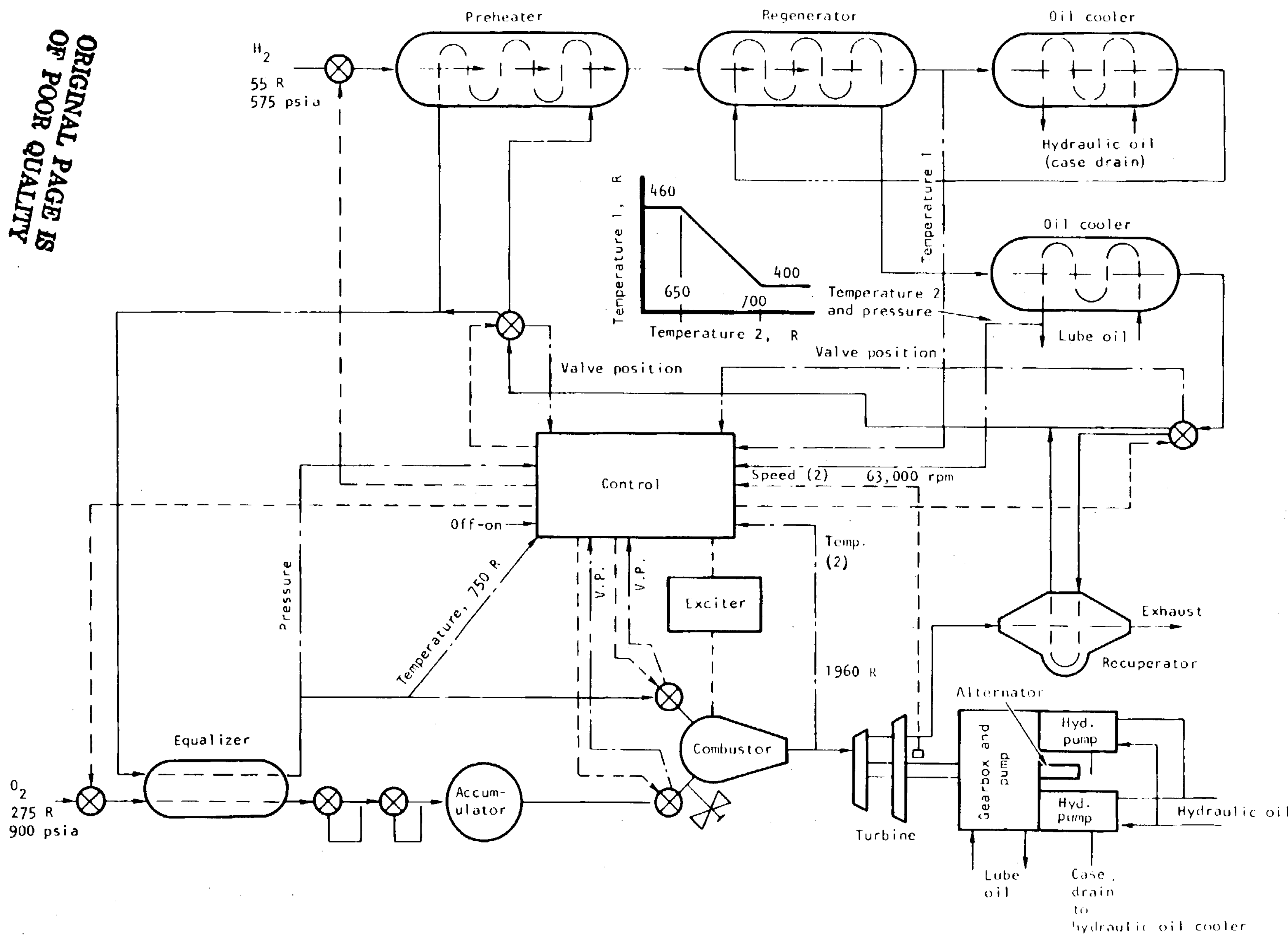

Figure 1.--Reference System.

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Each bypass loop is controlled by a three-way modulating valve. The two valves are electronically coupled in the control to prevent undesirable interaction.

Two redundant pressure regulators are employed in the oxygen circuit, since a single one sticking open may result in an overtemperature. They are both located downstream of the temperature equalizer in order to maintain supercritical pressure and avoid two-phase flow in the equalizer. An accumulator is located downstream of the regulators in order to provide more equal stiffness in the hydrogen and oxygen control system, compensating for a somewhat slow pressure regulator response (100 msec). A shutoff valve is located between the combustor and the control valve. Retention of oxygen at approximately 500 psig between the two valves effectively prevents backflow. The hydrogen and oxygen control valves are electrically linked in the control. An exciter is used to energize the combustor spark plug during start and whenever the turbine temperature is below 900 R, the set point, and the system is turned on. The combustor delivers hydrogen-rich combustion products to the turbopower subsystem.

The turbine is a two-stage supersonic axial-flow design. The design speed is 63 000 rpm with a turbine inlet temperature (TIT) of 1960 R using V-57 alloy turbine wheels. (The test system turbine is designed so that it can be retrofitted with Astroloy wheels and operated at 70 000 rpm and 2060 R TIT.

The electronic control functions can be divided into primary and secondary. The primary control functions are to hold the TIT, rpm, and equalizer outlet temperature constant by modulation of the hydrogen bypass and control valves. The secondary control functions are start-and-stop sequences, overspeed (rpm) and overtemperature (TIT) limits. It also effects automatic shutdown when lube pressure and temperature limit bands are exceeded; hydrogen supply pressure is too low; when the difference between the temperature and overtemperature thermocouple exceeds the specified band; and when an overspeed is sensed. The system specifications are summarized in table 1.

TABLE 1

SUMMARY OF SYSTEM SEPCIFICATIONS

Peak power	400-hp gearbox shaft output
Minimum power	0-hp gearbox shaft output
Output pads	2 pump pads at 5000 rpm 1 generator pad at 12 000 rpm
Turbine speed	63 000 rpm ± 1 percent steady state, ± 5 percent transient
Turbine inlet temperature	1960 R
Hydrogen inlet temperature to APU	55 to 560 R
Hydrogen inlet pressure	575 psia
Oxygen inlet temperature to APU	275 to 560 R
Oxygen inlet pressure	900 psia
Design life	1000 hr hot operation (900 cycles) and 2000 hr on inert gas checkout (600 cycles)
Cooling capability at 400 hp (heat sink for hydraulic system)	5000 Btu/min
Potential cooling with integrated tank pressurization 400 hp	15 000 Btu/min
Estimated dry weight	280 lb

DESCRIPTION OF APU-T

APU-T

The APU-T is a close-coupled experimental test version of the reference system and is schematically the same as the reference system to allow the investigation and demonstration of the technology required for a flight-type APU. Special design features and control options are included.

Provisions in the controller permit operation at moderate rpm, TIT, and combustor pressure. The capability to improve system efficiency by increasing the combustor inlet temperature from 750 to 900 R also is provided. The APU-T system is protected through automatic shutdown in the event control values are exceeded or component failures occur that are not critical or would not cause shutdown of the flight system.

The APU-T (see fig. 2) utilizes flight-type[a] components except as listed below:

(1) The turbine bearing seal is a labyrinth seal with externally supplied nitrogen buffer gas. To avoid seal development, the flight-type face seal was not used.

(2) An external lube oil pump supplies the turbine and gearbox.

(3) Provision to prevent heat soakback at shutdown is included in the reference turbine design, but the development of a heat sink/barrier was not carried through into the APU-T turbine. Instead, the APU-T lubricant flow is from an external source and can be maintained after shutdown.

(4) The gearbox is not designed for zero-g flight capability, is not flight weight, and has two pump pads, but no alternator pad.

(5) The recuperator is designed for ground test in which internal pressure is reduced to vacuum and the external pressure is ambient.

The APU-T components generate energy losses and these are partially recovered in the heat exchangers with some losses occurring because of radiation and convection, as illustrated in fig. 3. The concept of the recuperator is depicted where turbine exhaust energy is utilized in the cycle hydrogen flow as a means of cooling component heat loads. The operation of the APU-T test system is identical to the reference system with the hydrogen inlet

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[a]Flight-type components are similar in size, weight, and dynamic characteristics and have received sufficient evaluation to provide reasonable assurance that they are capable of being qualified for the required flight application with only minor modifications.

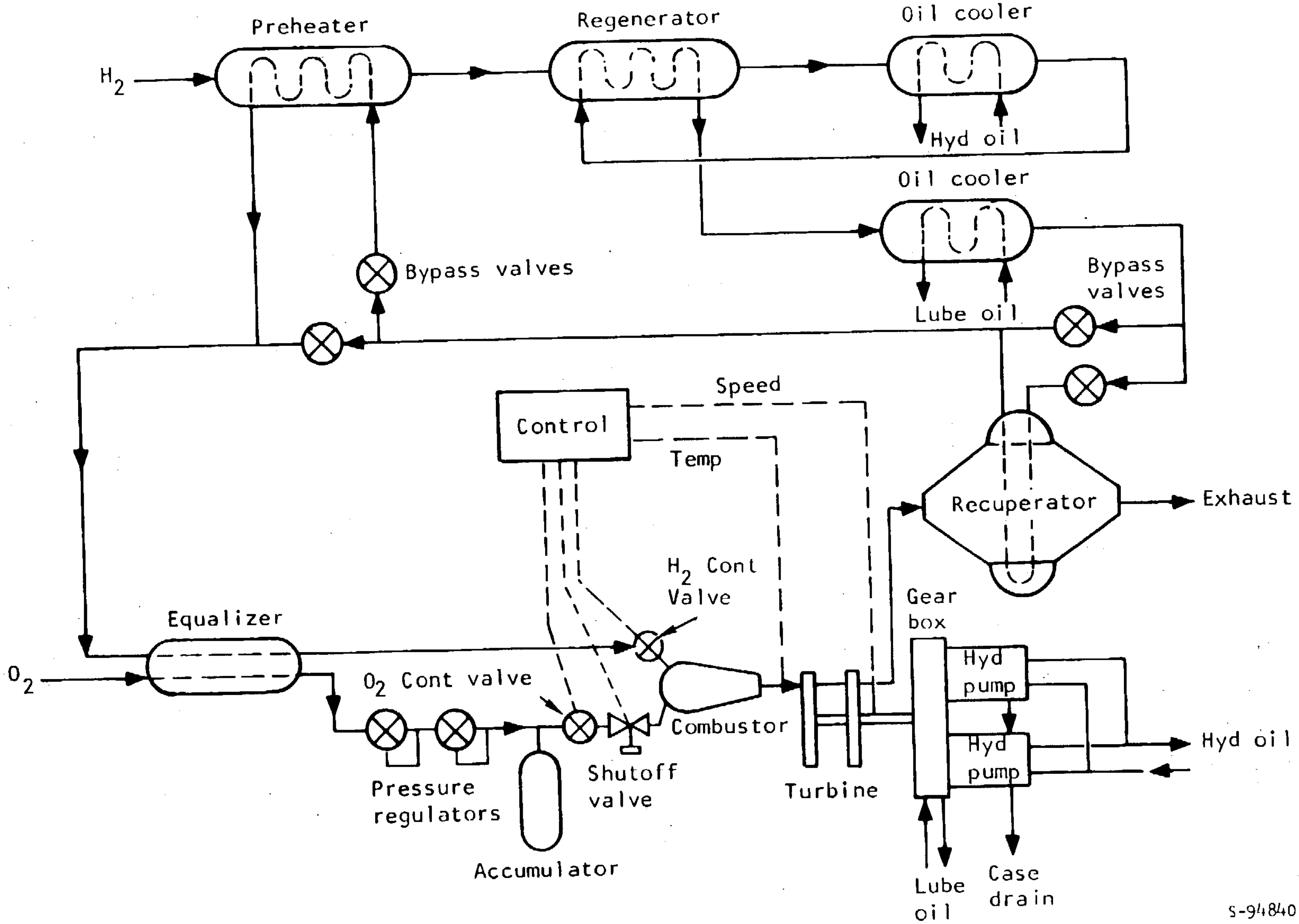

Figure 2.--Schematic of APU-T.

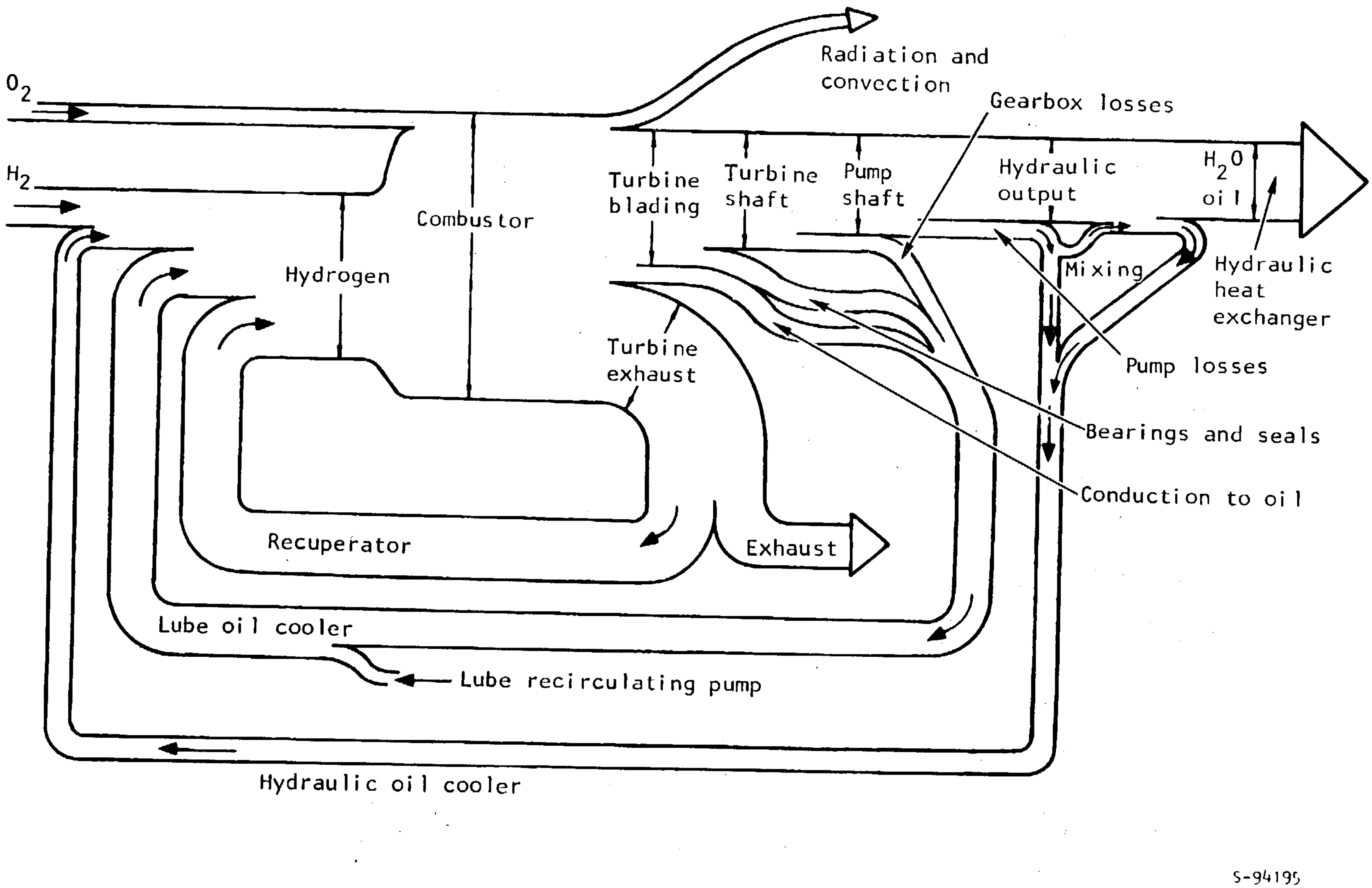

Figure 3.--Energy Flow Diagram H_2-O_2 APU-T.

temperature to the combustor controlled to 750 R and the hydrogen inlet temperature to the hydraulic oil cooler controlled to 460 R. Additionally, turbine speed is controlled to 63 000 rpm with a TIT of 1960 R.

The APU-T shown in fig. 4 is packaged for ease of component and instrumentation accessibility and installation, without strict regard to weight and volume. The controller is not included in the package because it is located in the control room and is connected to the APU-T by an umbilical cable.

The APU-T assembly is composed of the following two major subassemblies:

(1) Turbine-gearbox-pump assembly, which contains the combustor and oxygen flow control valve, the oxygen shutoff valve and accumulator, and the oxygen regulators. All of these components are mounted on the gearbox support structure.

(2) The heat exchanger assembly, which includes all heat exchangers and bypass valves, and a separate support structure.

The above two subassemblies were combined into the complete APU-T by brazing three interface joints: the oxygen line, the hydrogen line, and the turbine exhaust duct.

The entire assembly mounts on a base structure serving as both a test stand and a structure to support the assembly during transit and handling by forklift. Joints in the hydrogen and oxygen circuits in the entire APU-T are welded or brazed. Some mechanically sealed joints exist in the turbine, valves, and certain instrumentation connections. Two hydroformed bellows are used in the duct between the turbine discharge and the recuperator to allow for thermal expansion. All other piping expansions are compensated by loops and bends in the piping. Each heat exchanger is mounted by a single fixed point, with other support points flexible to allow for expansion. All components are mounted for a 1-g, 1-direction environment. The APU-T components and piping are located so that there is adequate access for instrumentation. Descriptions of the test setup and instrumentation are in a subsequent section, APU-T System Tests.

APU-T Propellant Feed and Conditioning Subsystem

Combustor.--The hydrogen-oxygen combustor delivers a controlled flow of hot gas to the turbine at uniform temperature and pressure as demanded by the APU system power level. It uses inputs of gaseous hydrogen and oxygen conditioned by the APU system heat exchangers. The combustor was designed to provide efficient combustion of fuel-rich gaseous hydrogen-oxygen mixtures for the following requirements:

(1) Good mixing within a short distance

(2) Wall temperatures compatible with common high-temperature structural materials

(3) Operation over a turndown ratio of at least 10:1

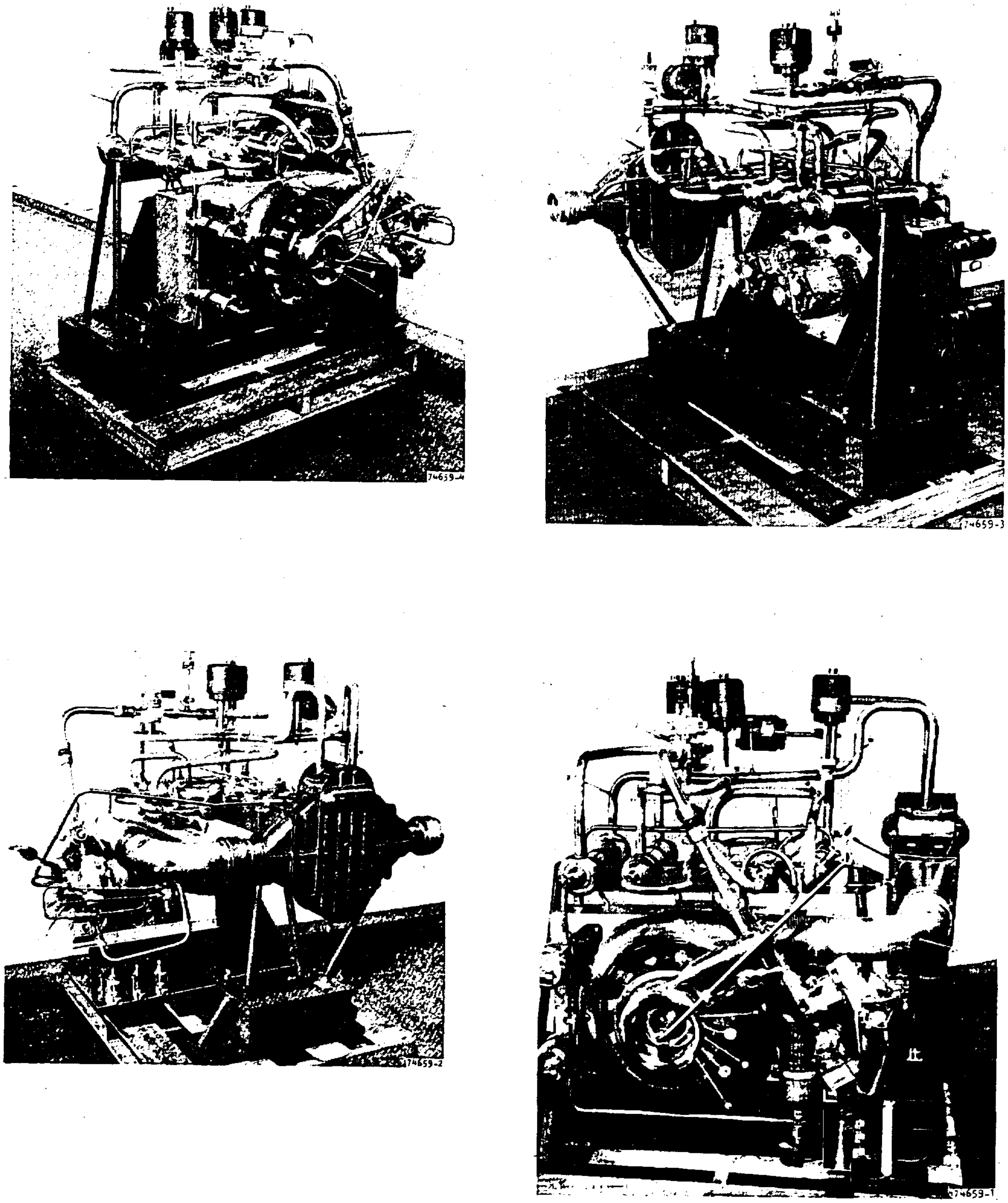

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Figure 4.--APU-T Assembly.

(4) Operation over an oxidizer-to-fuel ratio range of 0.4 to 0.9

(5) Reliable ignition at startup

(6) Capability of immediate relight in the event of flameout

These requirements were met with a prototype combustor (fig. 5) built in several pieces and bolted together to facilitate examination, modification, and assembly. Results of combustor testing were reported (ref. 1). For completeness, the prototype design and test results are summarized in this section.

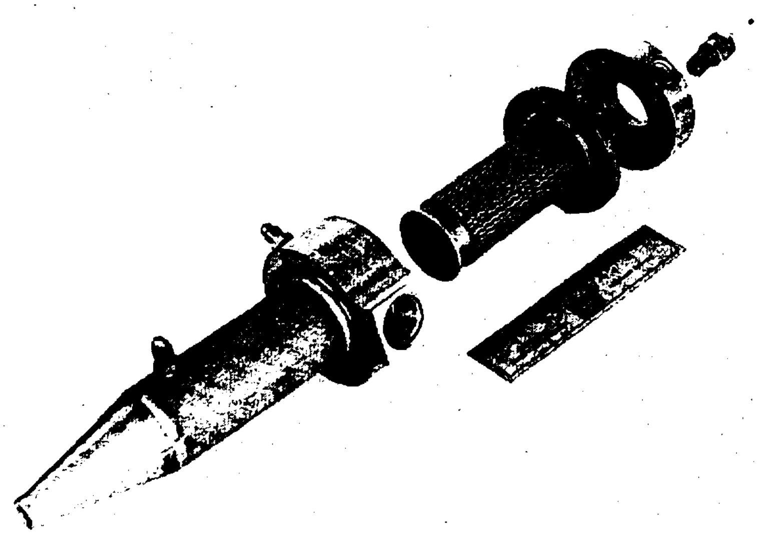

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Figure 5.--Hydrogen-Oxygen Combustor (Prototype Test Unit).

The APU-T combustor design is shown in fig. 6. Oxygen is fed into an annular manifold in the head of the combustor surrounding the spark plug cavity; then it is metered through eight nozzles that are arranged in a circle in the injector head and that discharge parallel to the combustor axis. A ninth oxygen passage leads from the oxygen manifold to the spark plug cavity.

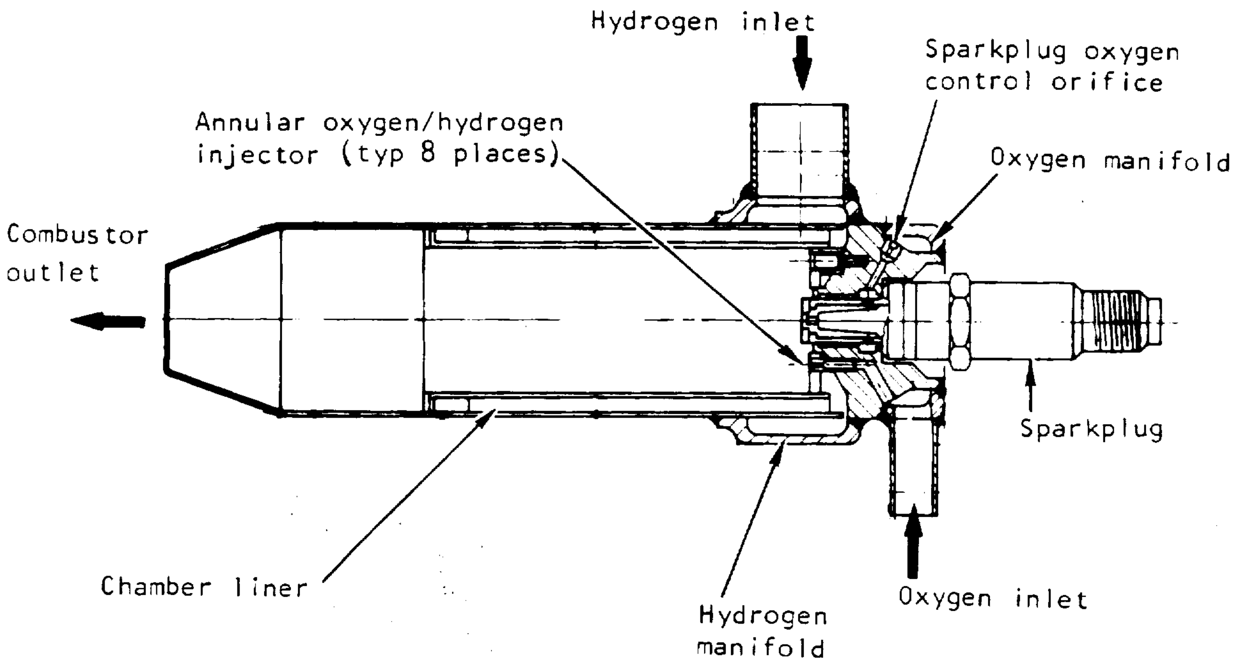


Figure 6.--Sectional View of the APU-T Hydrogen-Oxygen Combustor.

Hydrogen is fed into a larger annular manifold in the combustor head immediately downstream of the oxygen manifold. From there, approximately 40 percent of the flow is directed into the cooling jacket (described later) and the remaining 60 percent passes through the eight annular openings that surround the oxygen jets. Thus, the combustor burner has eight annular hydrogen-oxygen jets with the hydrogen on the outside. The oxygen is completely consumed before it can contact any hot metal parts.

The combusted gas mixture resulting from the main burner has a mixed temperature of approximately 2650 R, which is too high to be allowed to contact uncooled walls. Therefore, the combustion chamber is surrounded by a copper liner that has an extended heat transfer surface of expanded metal fins brazed on its o.d. The previously mentioned cooling hydrogen flows past these fins and maintains an allowable wall temperature on the copper liner. After the cooling hydrogen has passed through the fins, it is injected into the combusted gas stream to provide additional mixing and further cooling.

This type of combustor is inherently capable of operation over wide pressure and oxidizer-to-fuel ratio ranges. The combustion zones are identical in principle to the common gas burner jet except that the oxidizer is the inner jet in this combustor. The length of the jet increases as the oxidizer-to-fuel ratio range is increased, just as a gas stove jet increases when the gas (inner jet) flow is increased. Chamber pressure has no effect upon the length of the jet, so combustor operation essentially is independent of chamber pressure throughout the desired region of operation.

The combustor is made entirely of type-347 corrosion-resistant steel except for the copper liner assembly. The prototype test unit, built in several pieces and bolted together, was reworked to the design as shown in fig. 6 and welded together so the combustor body and manifold were a one-piece assembly. In the APU-T system performance tests, the combustor temperature was controlled to a fixed value of 1960 R.

On startup, ignition was obtained from a spark plug in which oxygen gas was fed through the annulus between the electrode insulator and the spark plug body into the combustor. The oxygen was ionized by the spark causing the jet issuing from the spark plug to ignite and form a pilot light for the remaining jets in the combustor during startup. The spark was terminated when the turbine inlet temperature reached 900 R.

During APU-T system tests, problems occurred with this ignition design. Essentially, the combustor spark plug and the threaded area around the plug experienced damage during initial tests. It was concluded that the spark plug was breathing hot products of combustion because of combustor pressure fluctuations. The electrode end of the plug became hot enough to initiate a fire fed by the oxygen supplied to the plug. Thus, the combustor design was modified to that shown in fig. 7 so that a separate tube fed oxygen to the spark plug rather than the combustor oxygen manifold. Also, two valves were used to sequence gaseous oxygen or hydrogen to the spark plug. A short gaseous nitrogen purge separated the flow of gaseous hydrogen and oxygen. Gaseous oxygen was injected during lightoff and then gaseous hydrogen was injected through the spark plug to cool it and prevent it from breathing hot combustion products.

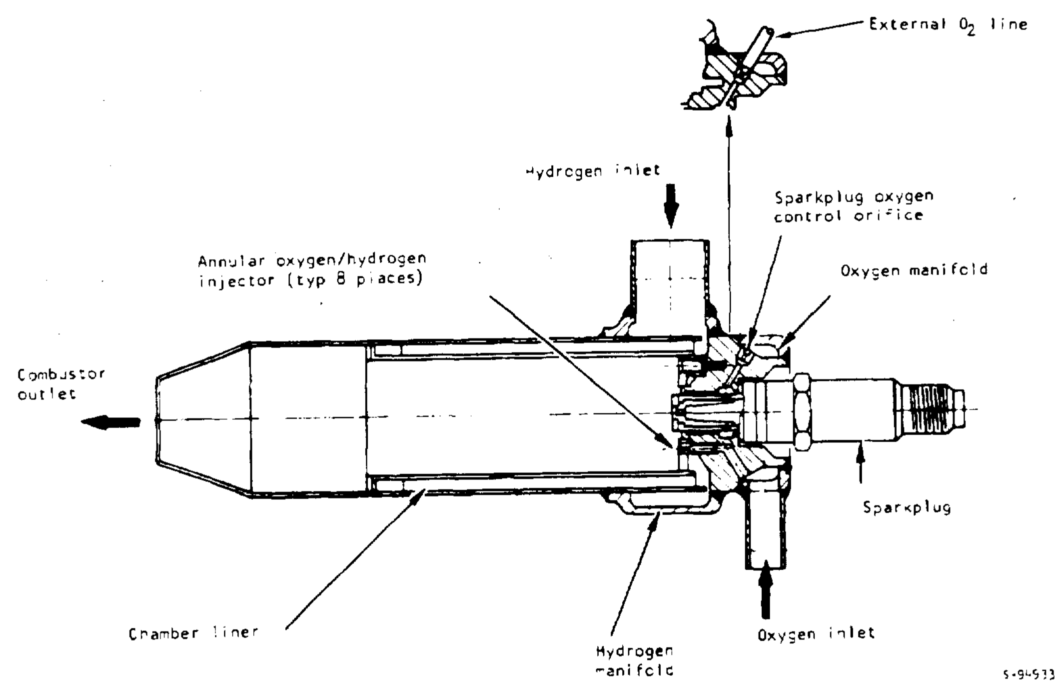


Figure 7.--Sectional View of the Modified APU-T Hydrogen-Oxygen Combustor.

Spark plug tip melting reoccurred near the end of APU-T system tests after about 9 hr successful operation with the modified design of fig. 7. A design modification was made and is shown in fig. 67. The test program was terminated before the validity of this solution described in the section, Analysis of Test Results, Combustor, could be demonstrated.

The H_2-O_2 ignition system, which provides spark plug ignition of the combustor, is shown in fig. 8. The ignition unit consists of a commercial capacitive discharge ignition system cycled by a multivibrator and controlled from the H_2-O_2 APU-T controller. The ignition current to the spark plug is sensed using an induction coil around the high tension lead and the signal provides an input to the H_2-O_2 APU-T controller to confirm sparking.

The ignition system is cycled at a rate of 30 Hz and is powered from a 12-Vdc supply, 5-A maximum. Typical open circuit secondary voltage at 30 Hz is 50 000 V. The capacitive discharge unit is of solid-state construction using silicon controlled rectifier (SCR) switching.

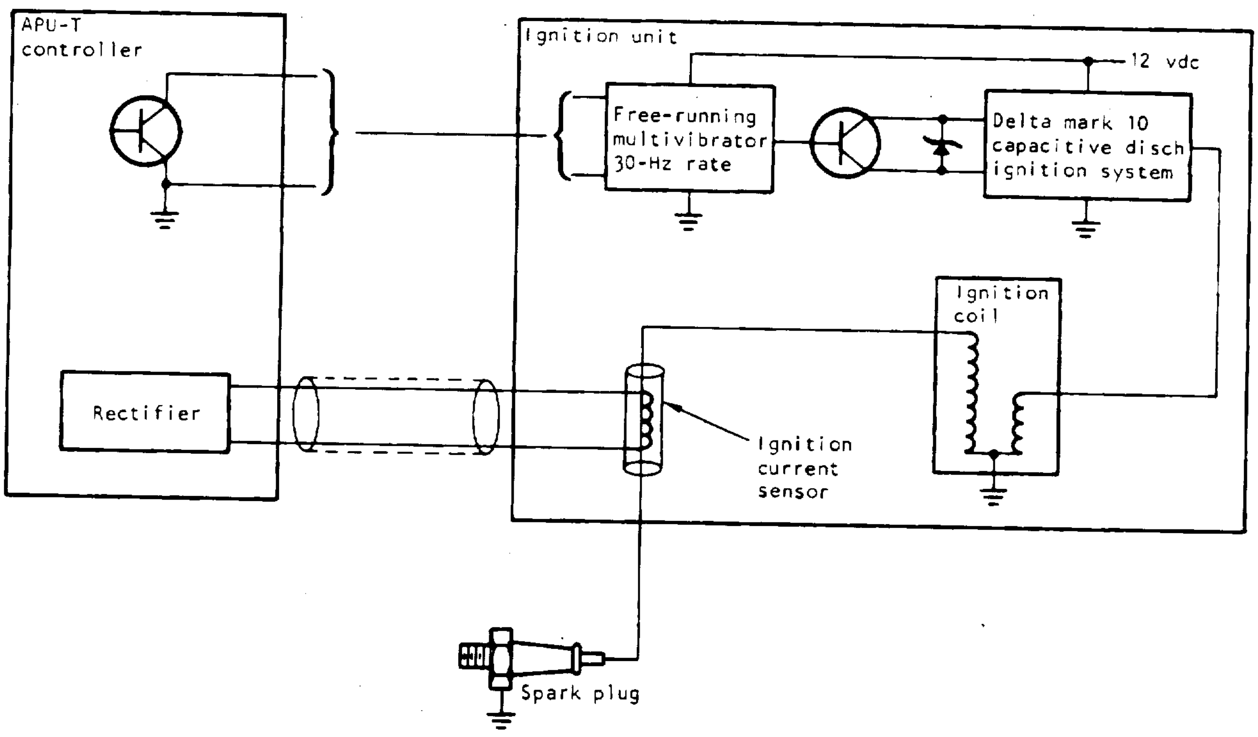


Figure 8.--H_2-O_2 APU-T Igniter Schematic.

System heat exchangers.--Six heat exchangers are used in the Subsystem H_2-O_2 APU: the lubricating oil and hydraulic coolers, the preheater and the regenerator, the recuperator, and the equalizer. Becasue of economic considerations, the lubricating and hydraulic oil coolers are identical, and the preheater and the regenerator are identical. The heat exchangers (fig. 9) are designed for 1000 start-stop cycles, with the heat transfer design points described below.

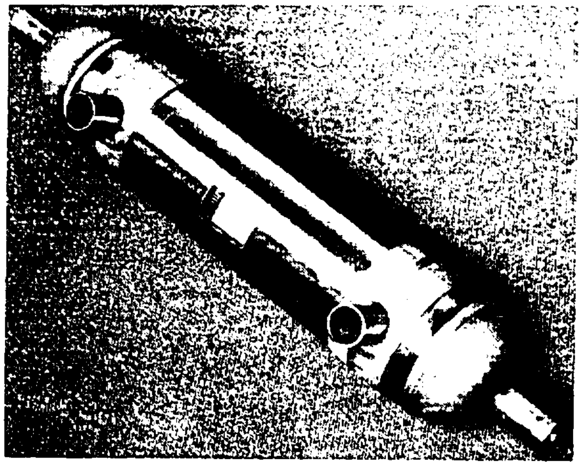
Lubricating and hydraulic oil cooler: The lubricating and hydraulic oil coolers cool the lubricating and hydraulic oil with hydrogen which has been conditioned to acceptable temperatures by the preheater and the regenerator. The heat transfer design point for the cooler is shown in table 2.

The lube/hydraulic cooler is a tube and shell multipass crossflow heat exchanger. In both applications, the overall flow direction is counterflow. The hydrogen inside the tubes makes a single pass through the heat exchanger and the shell side fluid flows across the tube bundle four times.

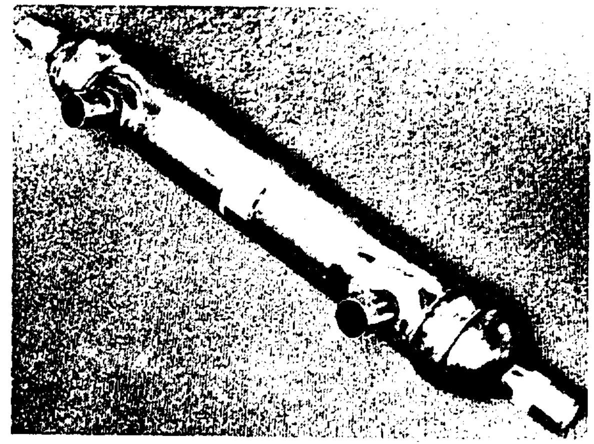
TABLE 2

LUBE/HYDRAULIC COOLER HEAT TRANSFER DESIGN POINT

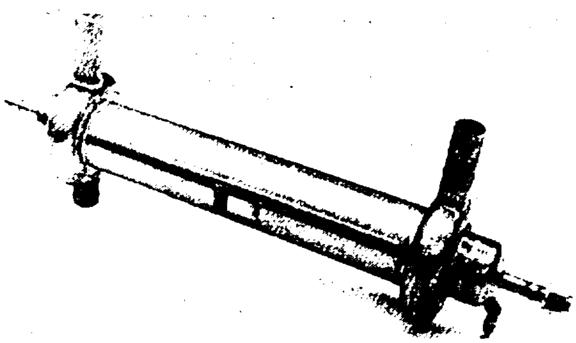
	Cold side	Hot side
Fluid	Hydrogen	MIL-H-83282
Flow rate, lb/min	1.026	52
Inlet temperature, R	400	775
Outlet temperature, R	758	733
Inlet pressure, psia	600	200
Core pressure drop, psid	0.098	1.70
Effectiveness	0.953	0.112
Duct diameter, in.	1.0	1.0
Total heat transferred, Btu/min	1282	



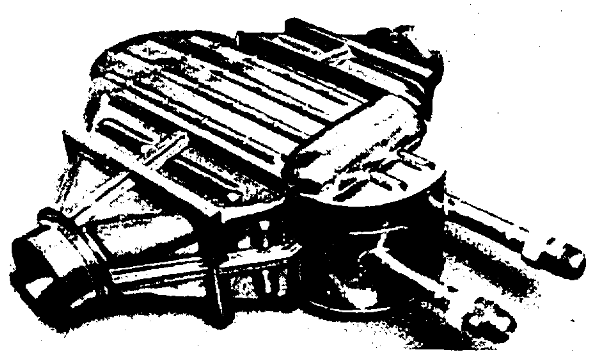
APU-T preheater/regenerator



APU-T lube/hydraulic cooler



APU-T equalizer



APU-T recuperator

Figure 9.--System Heat Exchangers.

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Preheater and regenerator: A single heat exchanger design is used for the preheater and regenerator applications. The preheater warms up the cryogenic hydrogen to an acceptable temperature so that, after passing through the regenerator, the hydrogen represents an acceptable heat sink for the hydraulic oil. The heat source for the preheater is hot hydrogen from the recuperator. The regenerator cools the hydrogen after it has absorbed the hydraulic heat load so it is at a suitable temperature to cool the lube oil. The heat sink in the regenerator is the hydrogen outlet from the preheater. The heat transfer design point for the preheater/regenerator design is the regenerator operating condition shown in table 3.

The preheater/regenerator is a tube and shell multipass crossflow heat exchanger. In the preheater configuration, the overall flow direction is counterflow, whereas in the regenerator application, the unit is operated in parallel flow. The hydrogen inside the tubes makes a single pass through the heat exchanger, and the shell side hydrogen flows across the tube bundle six times. One header plate is fixed, and the other incorporates a sliding joint that eliminates thermal expansion problems.

TABLE 3

PREHEATER/REGENERATOR HEAT TRANSFER DESIGN POINT

	Cold Side	Hot Side
Fluid	Hydrogen	Hydrogen
Flow rate, lb/min	1.026	1.026
Inlet temperature, R	88	755
Outlet temperature, R	400	420
Inlet pressure, psid	600	600
Core pressure drop, psid	0.0756	0.0867
Effectiveness	0.468	0.502
Duct diameter, in.	1.0	1.0
Total heat transferred, Btu/min	1237	

Temperature equalizer: The hydrogen-oxygen temperature equalizer functions to bring the temperature of the two propellant flows to nearly the same level at the inlet to the propellant flow control valves so that the turndown rate is reduced, thereby facilitating system control. A vented buffer zone is provided between the hydrogen and oxygen passages, thus precluding mixing of the two fluids in the unlikely event of a leak in one of the fluid passages. The heat transfer design point for the temperature equalizer is shown in table 4.

The temperature equalizer is an annular plate fin heat exchanger. Three concentric finned passages are provided. The inner passage carries the oxygen, and the outer the hydrogen. The middle passage separates the two fluids and is vented, thus providing a buffer zone between the two highly reactive fluids. The heat exchanger is constructed of stainless steel except for the heat transfer fins, which are copper. This fin material was selected from thermal performance optimization considerations.

TABLE 4

TEMPERATURE/EQUALIZER HEAT TRANSFER DESIGN POINT

	Cold side	Hot side
Fluid	Oxygen	Hydrogen
Flow rate, lb/min	6.034	8.422
Inlet temperature, R	300	708
Outlet temperature, R	662	689
Inlet pressure, psia	675	507
Core pressure drop, psid	1.50	8.16
Duct diameter, in.	0.5	1.0
Total heat transferred, Btu/min	569	

Subsystem recuperator: The recuperator operates with hydrogen on the cold side and turbine exhaust gas on the hot side. It provides sufficient heat input into the cycle for propellant thermal conditioning and improves cycle thermal efficiency by recovering waste heat from the turbine exhaust. The design point for the recuperator (table 5) was established by system analysis.

The recuperator is a box and U-tube design. The exhaust gas from the turbine flows in a single pass through the shell side of the heat exchanger. This minimizes the pressure drop in the exhaust gas stream. The hydrogen flows in cross counterflow through the tubes of the unit. This flow arrangement allows the box structure to be lightly pressure-loaded by the exhaust gas and the high pressure hydrogen is contained within the tubes of the heat exchanger.

TABLE 5

RECUPERATOR DESIGN POINT

	Cold side	Hot side
Fluid	Hydrogen	Hydrogen-steam (60-40 by mass)
Flow rate, lb/min	8.43	14.47
Inlet temperature, R	503	1366
Outlet temperature, R	1122	785[a]
Inlet pressure, psia	600	16.8
Core pressure drop, psid	1.8	1.86
Effectiveness	0.717	0.673
Duct diameter, in.	1.0	4.0
Total heat transferred, Btu/min	18 059	

[a]Minimum allowable outlet temperature = 700 R

APU-T Turbopower Subsystem

Turbine.--The turbine for the -T system and the reference system is a two-stage, pressure-compounded, axial-impulse turbine rated at approximately 430 shp at 63 000 rpm. Aerodynamically, both designs are identical, with the APU-T turbine mechanical design simplified to eliminate a development effort and increased cost. The significant design features of the APU-T turbine are discussed below.

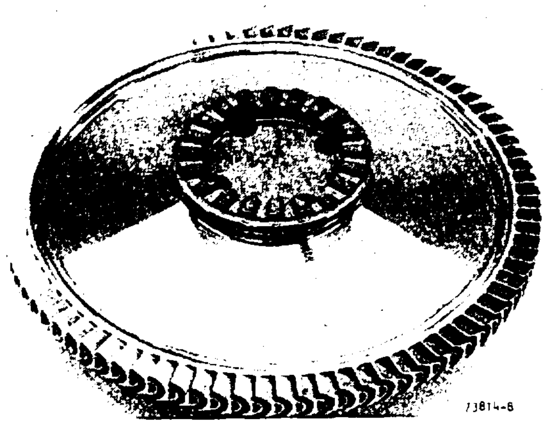
The pertinent physical and design characteristics of the turbine are summarized in table 6. Expansion through the turbine occurs with partial-admission supersonic stages.

The hot gas from combustion of hydrogen and oxygen expands through the six axisymmetric first-stage nozzles into the first rotor blades (fig. 10a). Leaving the first-stage wheel, the gas enters an interstage plenum prior to expansion through 24 two-dimensional, second-stage nozzle channels. At the second-stage nozzle entrance, the gas is at an intermediate pressure and expands to the outlet pressure level before flowing through the blades of the second-stage wheel (fig. 10b). After leaving the second-stage wheel, the gas enters the discharge plenum through a channel, thus providing some diffusion recovery of the rotational energy in the medium.

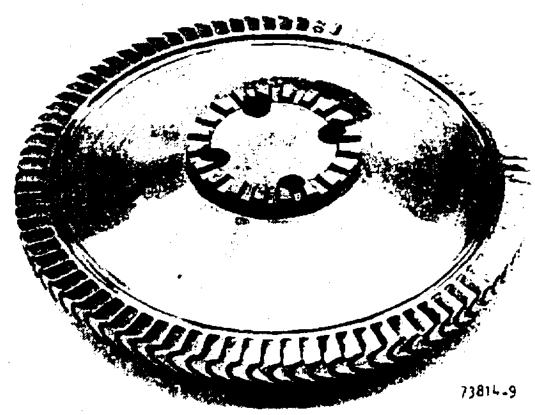
TABLE 6

TURBINE DESIGN PARAMETERS

	First Stage	Second Stage
Effective nozzle throat area, sq in.	0.1517	0.6300
Nozzle exit area, sq in.	0.2335	0.6930
Nozzle type	Axisymmetric	Two-dimensional
No. of nozzles	6	24
Admission, percent	29	60
Bucket height, in.	0.265	0.330
Axial chord length, in.	0.350	0.350
No. of blades	85	85
Pitch diameter, in.	5.566	5.631
Nozzle angle, deg	16.0	16.0
Bucket inlet angle, deg	23.0	23.0
Bucket exit angle, deg	21.7	21.7



a. First-stage turbine wheel



b. Second-stage turbine wheel

Figure 10.--First-and Second-Stage Turbine Wheels.

The mechanical design of the turbine included consideration of the turbine aerodynamics, thermal management, stress analysis, and metallurgical problems, all of which influenced the final configuration. Important parameters influencing the mechanical design were close tip clearance (0.010 in.), use of a hydrogen-rich working fluid, avoidance of heat soakback after shutdown, and long-life requirements including many starts and stops.

It was initially intended that the APU-T turbine would be the same as the reference system turbine, but because of budgetary problems and the desire to avoid a development effort, the APU-T turbine mechanical design was simplified. The resulting design is illustrated in figs. 11 and 12. The APU-T turbine major design changes from the reference system turbine were a change in the turbine bearing seal and removal of the heat soakback thermal barrier.

Early in the design of the reference system turbine, the use of carbon-face-type seals was considered to prevent oil from leaking into the turbine cavity. This face seal would have required a normal development with extensive turbine testing and several assembly-disassembly cycles. Because of the development costs involved, this type bearing seal was replaced with a labyrinth seal pressurized by nitrogen gas for the APU-T turbine. In the APU-T tests, nitrogen buffer gas was introduced under pressure in the center of the labyrinth seal, and its flow in both directions prevented oil from leaking to the outside and hydrogen-water vapor mixture from entering the bearing cavity.

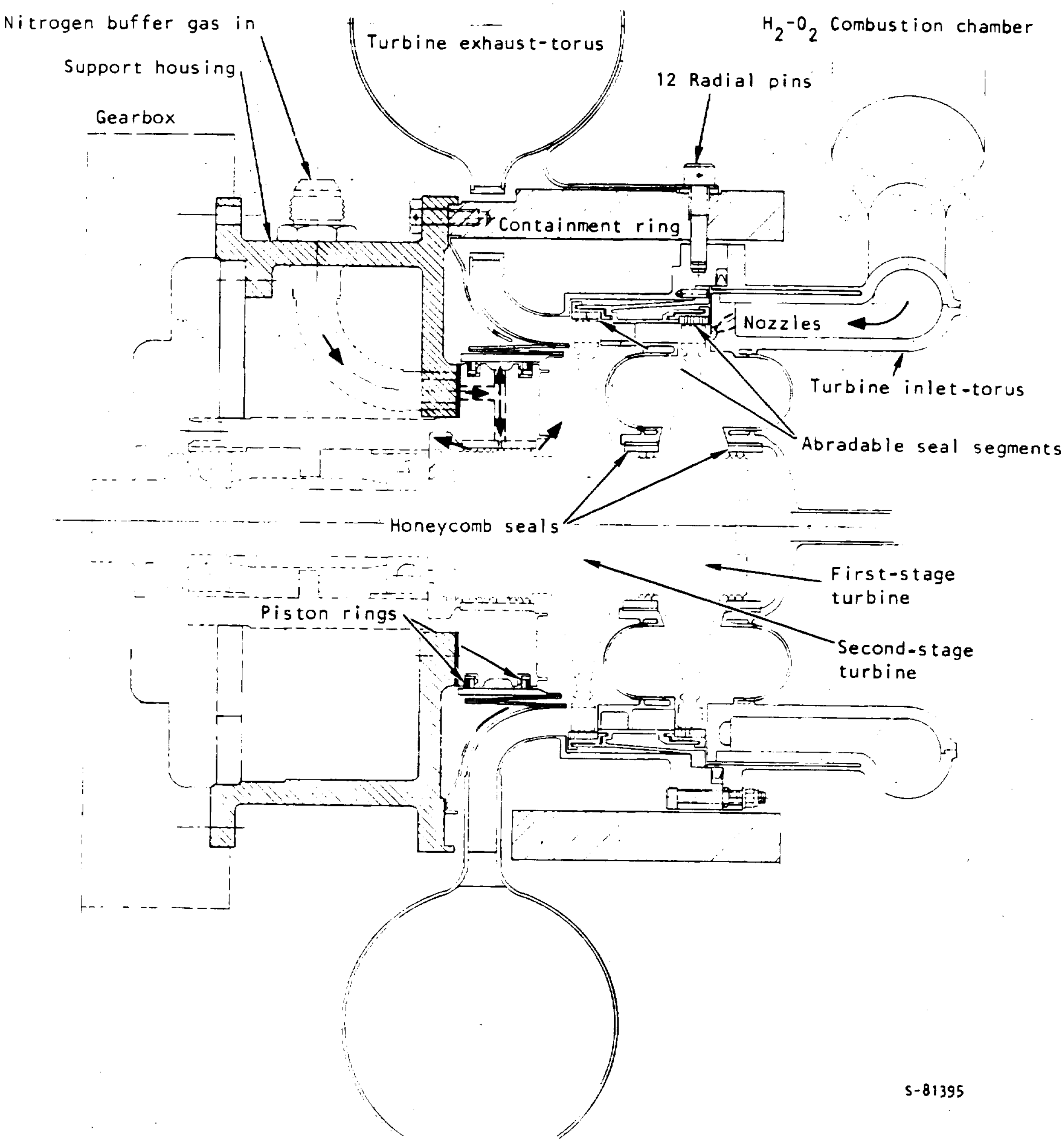


Figure 11.--Turbine Supporting Structure.

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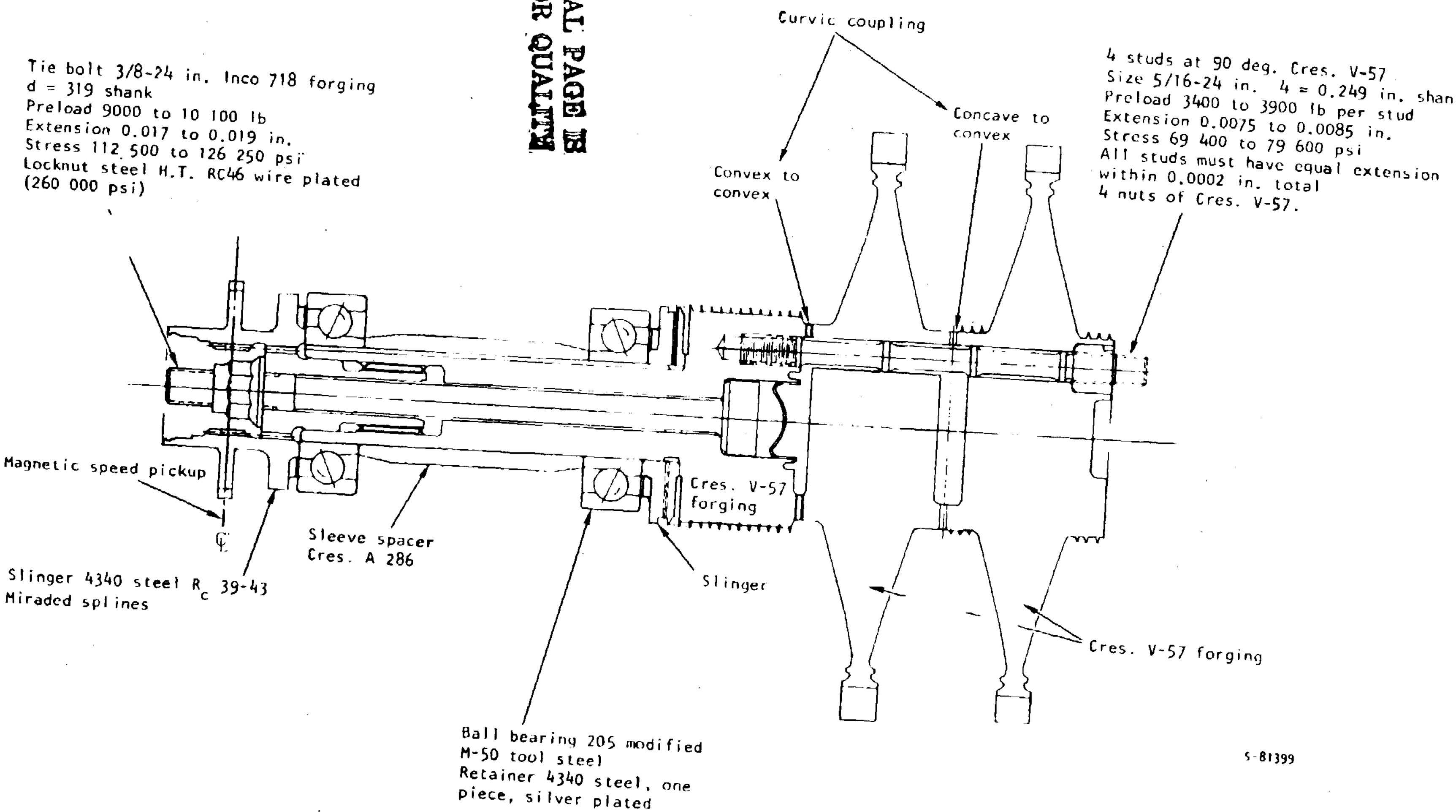

Figure 12.--Turbine Rotating Assembly.

In the reference system turbine design a thermal isolation package limits the post-shutdown heat soakback from the turbine to the bearing cartridge. This package would have required some additional normal development. Because the APU-T turbine lubricant flow from an external source could be maintained after shutdown, the thermal barrier was removed.

In the mechanical design of the turbine, the first-stage turbine wheel is mounted to the second-stage wheel, and the two are attached to the shaft by four studs. Centering and power transmission is accomplished by curvic couplings. The four studs are loaded in tension. Each nut is supported by the turbine wheel, thus preventing loading of the stud end caused by centrifugal force. Lands on the studs provide support for the stud in the wheel during rotation.

The spline coupling, bearing, and bearing spacer are held in place by a center tie bolt loaded in tension, which stiffens the rotating assembly. In this way, the shaft effective diameter in bending is increased to approximately that of the ball bearing inner race.

The two turbine wheels, the four studs and nuts, and the shaft are made of CRES V-57 steel, a modified CRES A286. The central tie-bolt material is INCO 718 stressed to about 126 000 psi. To protect it from the hydrogen environment, a cap is welded to the shaft end. Both ball bearings are made of M-50 tool steel and have a silver-plated 4340 steel separator.

The turbine assembly is supported from the gearbox by a support housing, which is attached to the gearbox housing by a flange and 12 0.25-in.-dia bolts. The bearing carrier is bolted to the support housing by six 10/32-in. screws. Shims are provided between the bearing carrier and support housing to adjust the axial clearance between the first-stage turbine and nozzle. The support housing is bolted to the containment ring, which reaches through the holes in the turbine outlet torus by means of six lugs. Because the containment ring is cooler, it is used to provide support and guidance for the turbine housing. The hot turbine housing is supported from the containment ring by 12 radial pins. These pins permit radial growth of the turbine housing and at the same time maintain the concentricity of the hot turbine housing relative to the containment ring and the rotating assembly. Because the turbine housing expands and contracts with temperature, all connections between it and any cooler structure must have flexibility.

In addition to the allowance for radial dimensional changes between parts, provision is made for their free axial growth. The radial pins in the containment ring establish the axial location for the inlet torus and leave the turbine outlet torus free to move. When this occurs, leakage of exhaust products is prevented by a double piston ring expansion joint. The nitrogen buffer gas used for the labyrinth shaft seal also is directed into the space between the two piston rings. The nitrogen gas pressure is higher than the ambient and higher than hydrogen outlet pressure, so nitrogen will flow outward in both directions and prevent leakage of hydrogen to the atmosphere.

To prevent a localized hot area in the first-stage nozzle torus, the hot gas from the combustor is introduced tangentially (fig. 13) downstream just beyond the last drilled nozzle. In this way, the hot gas must travel circumferentially almost 170-deg before entering the first nozzle, providing uniform heating of the nozzle torus. A similar feature is built into the second-stage nozzle assembly. The annulus between the inlet of the second-stage nozzle and the discharge of the first-stage turbine wheel permits circulation of hot gas.

Stationary segments installed over the turbine blade tips (segmented to provide for expansion) are fitted on the inner diameter with an abradable material that will wear readily if touched by the rotating turbine blades. In the same way, the three labyrinth seal stators will wear to establish a running clearance with the rotor. The stator of the shaft labyrinth is lined with bronze while the two turbine seals are made of 1/32 cell-size stainless steel honeycomb.

The rotating assembly is built up as a separate cartridge that can be installed or removed from the turbine housing. The second-stage nozzle ring is trapped between the two turbine wheels, and it is supported for balancing from the bearing carrier by a special assembly fixture. This fixture prevents damage to the intermediate labyrinth seal. The rotating assembly is dynamically balanced outside the turbine in a special balancing fixture.

The ball bearings selected for the APU are 205-size angular-contact-type with relieved inner ring and outer land riding machined separator. The material is M-50 for the balls and rings and silver-plated steel for the ball separator. The nominal DN number is 1.575×10^6. The bearings are lubricated by directed

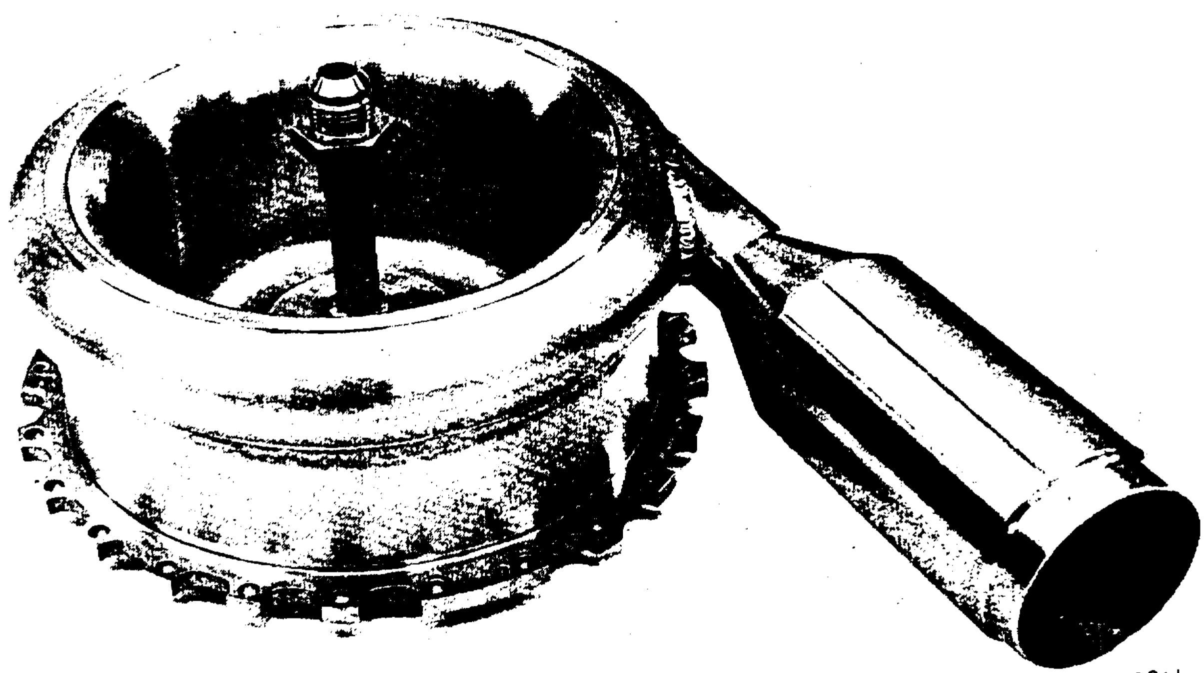

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Figure 13.--First-Stage Nozzle Housing.

flow from an oil jet and cooled by the same lubricating oil and also by the oil flowing under the bearing cores through slots cut on the shaft.

Gearbox and lubrication.--The APU-T gearbox was not designed for zero-g flight capability and was provided with two pump drive pads, but no alternator pad. It used many existing components to minimize tooling cost, because demonstration of the gearbox component was not necessary for the attainment of program objectives. The gear train design of aircraft-type gearing (manufactured for the Lockheed SST-ECS compressor) was utilized because it had been designed and tested to operate at comparable input speeds and horsepower.

The APU-T gearbox had the following design requirements:

(1) Two output pads for hydraulic pumps (5000 rpm)

(2) Input pad for the rotating assembly (63 000 rpm)

(3) Lubrication system suitable for laboratory unit

In addition, the size of the two ABEX hydraulic pumps dictated the center spacing of the two output gears. The output power from the gearbox was 400 hp.

The APU-T gearbox is a conventional two-stage reduction design and detailed drawings can be found in ref. 1.

The first-stage speed reduction (fig. 14) comprises an 18-tooth pinion, three 54-tooth planet gears with carrier, and a 126-tooth ring gear. This combination provides a reduction of 7:1, or an output speed of 9000 rpm. The carrier supporting the planet gears is nonrotating. An arrangement of a cluster of three planets around the pinion reduces the load on the pinion gear teeth and the radial loads on the pinion bearings. The pinion is supported by two ball bearings, preloaded in one direction by a coil spring. A quill shaft transmits the torque from the turbine to internal splines in the pinion. The torque from the pinion is divided between three planet gears that rotate on bushings about fixed pins in the carrier. The planet gears also engage the ring gear, made somewhat flexible by its small radial thickness and its external spline connection to the ring gear hub. Flexibility of the ring gear compensates for inaccuracies in the gear system, assuring more equal load sharing between the three planet gears.

The ring gear hub is pinned to the 9000-rpm pinion and held axially by a locknut on the end of the shaft. Torque from this gear is split equally between the two mating gears, and the speed is reduced to an output rpm of 5000 by the tooth ratio of 53:95. By placing of the two output gears symmetrically about the pinion, the load on the pinion bearings becomes negligible. The two shafts of the output gears are provided with internal splines for coupling to two ABEX hydraulic pumps.

As shown in fig. 14, the housing for the gearbox is made of two slabs of aluminum jointed together on the vertical face. All bearings are installed in steel bushings that are bolted and shrunk in the aluminum housing and line-bored in place. The steel planet carrier is attached to the turbine side

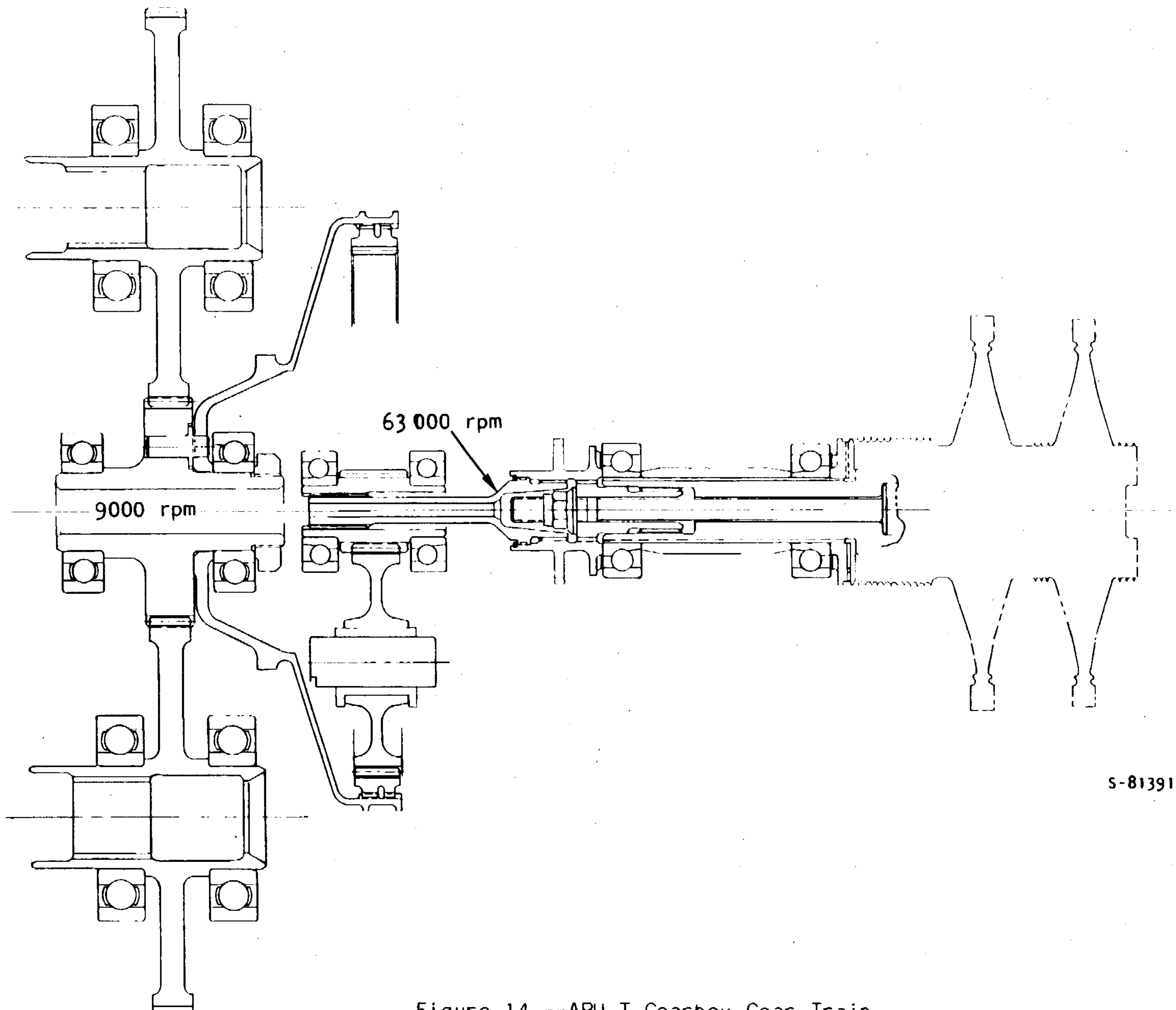

Figure 14.--APU-T Gearbox Gear Train.

aluminum housing and becomes the basis for the location of the other bearings. It carries the high-speed planet bearings and provides support for one of the 9000-rpm pinion bearings.

The gearbox and the turbine are lubricated by an external oil supply distributed to the gears and bearings as shown in fig. 15. Oil to the high-speed turbine bearings is supplied from the gearbox and enters the turbine bearing carrier via a coupling tube. In the turbine bearing carrier, one jet lubricates each bearing, and the oil is returned to the sump by means of an oil slinger. Oil for cooling the turbine bearings enters the tube shown at the left of fig. 15, flows through the tube shown at the left, and flows through the tube inside the 9000-rpm hollow pinion shaft to the high-speed pinion, where it jets into the hollow quill shaft. From the quill shaft, the oil enters the turbine shaft and flows through axial grooves under the two ball bearings and ball bearing spacer to the slinger, where it is pumped out and into the pump. Oil jets within the gearbox are provided for lubricating the 63 000-rpm pinion, the 9000-rpm gear, and the two bearings supporting this gear. The rest of the bearing and gears are splash-lubricated. The planet bushings are lubricated by internal passages in the planet carrier that feed oil to the three stationary pins.

The two ABEX hydraulic pumps are attached at the gearbox using standard accessory pads. To prevent oil from leaking into the pad cavity, each shaft is fitted with a carbon-face-type seal.

Hydraulic pumps.--The hydraulic pumps designated for the H_2-O_2 APU system were the Abex Model AP27V-3-02 series, in-line, axial-piston pressure-compensated, variable-delivery design. The pumps included a solenoid valve added to their port cap to provide depressurization.

For this Abex AP27V-series-type pump, the pistons are actuated by a variable lift cam. The cam angle that controls piston stroke is varied by a pressure compensated stroking piston. The compensator uses a pressure sensor and a three-way slide valve to control pressure to the cam angle control piston. The pressure compensator regulates outlet pressure within a small band for varying demand flow rates.

The axial thrust of the piston against the cam plate during compression stroke is balanced hydraulically. Positive piston hold-down is provided by a hold-down plate, retainer, thrust bearing and hold-down nut. They serve to maintain a preset clearance between the piston shoes and cam face for starting and with overrunning loads. Depressurization is accomplished by porting pressure from the outlet port directly to the stroking piston, bypassing the compensator.

Pertinent design characteristics of the pumps are summarized below:

Type: Abex Model AP27V-3-02

Theoretical displacement: 4.0 cipr (max.)

Speed: 5020 rpm

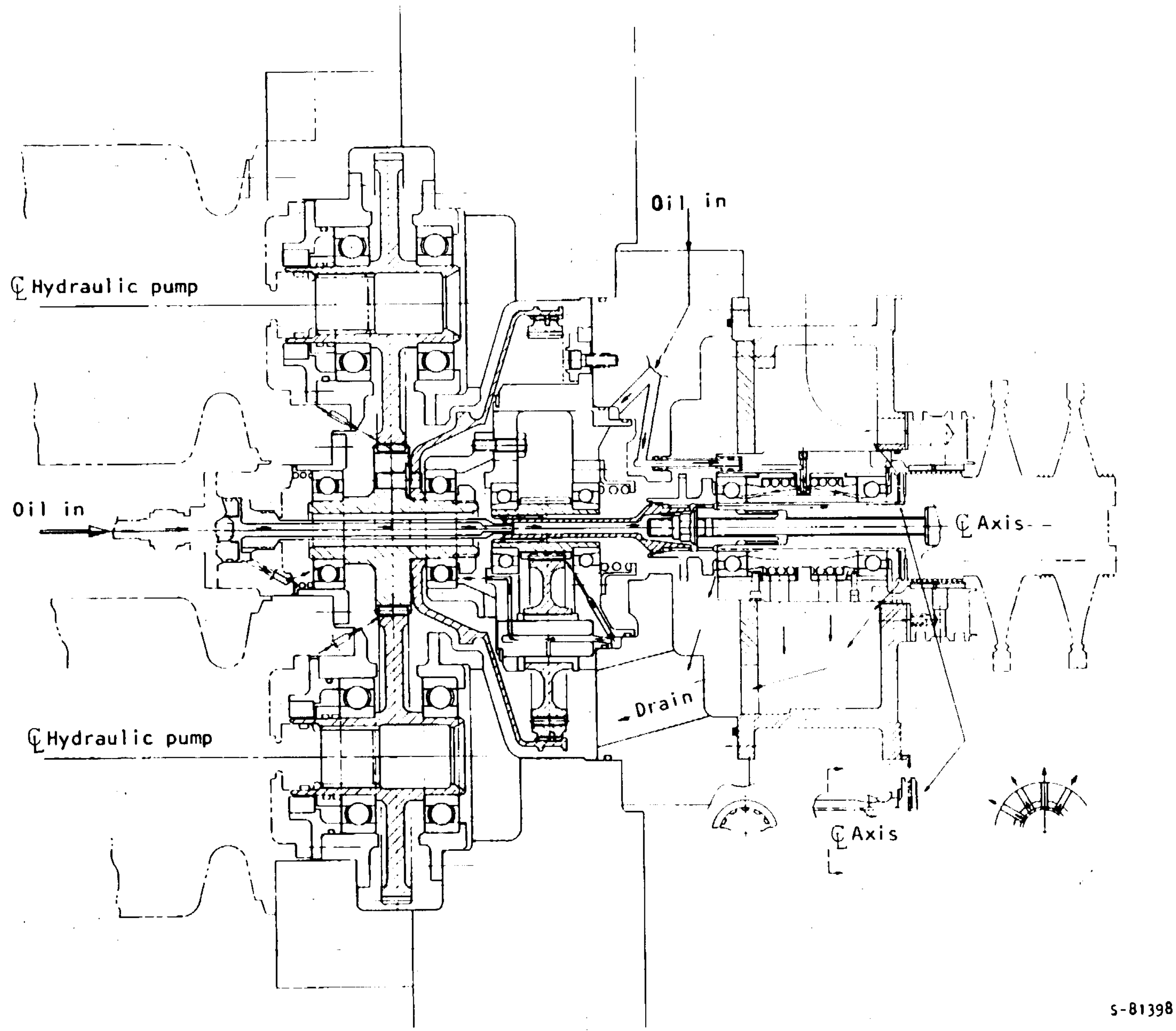

Figure 15.--APU-T Gearbox Lubrication.

Maximum delivery at 5020 rpm: 80 gpm at 3750 psig

Fluid: MIL-H-5606

Weight: 30 lb

Number of pistons: 9

Polar moment of inertia: 0.061 in.-lb-sec^2

Required inlet pressure: 60 psia

Hydraulic fluid temperature: 395 R to 700 R

During pump operation, the nine pistons reciprocate in the cylinder barrel. As the barrel rotates, the pistons reciprocate within their bores, intaking and discharging fluid through a stationary bearing surface on the port cap. The stroking piston is stabilized by the three-way valve in the pressure compensator at a position that provides a pump displacement consistent with system demand.

Prior to use in APU-T system tests, the two Abex AP27V-3-02 pumps were calibrated at hydraulic fluid inlet temperatures of 560 R and 700 R. After approximately 9 hr of APU-T tests, the pumps were damaged during a particular test series as shown in a subsequent subsection, Summary of Conducted Tests. The pumps were repaired and recalibrated. The data obtained prior to testing and after pump repair is shown in figs. 16 and 17 for the SN 109670 and SN 109671 pumps. The pumps delivered approximately 80 gpm for an input shaft power of 200 hp prior to repair. After repair, the delivery of SN 109670 changed slightly, particularly at the higher horsepower inputs, to require less input power for the same delivery.

The pump calibration data was used to determine test horsepower level from measured hydraulic flow. The calculation procedure and pertinent equations used in the data reduction of the APU-T system tests is outlined in Appendix A.

APU-T Control Subsystem

The control subsystem for the APU is an advanced electronic fuel propellant control (fig. 18). The subsystem meters both the hydrogen and oxygen flow to control turbine inlet temperature and turbine speed. It controls the hydrogen temperatures for the lube and hydraulic oil coolers to prevent freezing either the lube oil or the hydraulic oil. It provides temperature control of the propellants flowing into the combustor. It controls the startup and shutdown sequence required for system operation. The elaborate monitoring system detects faults, not only within the engine portion of the APU, but within the controller itself and provides a safe, swift shutdown of the entire system in the event of a malfunction.

The control subsystem comprises primary and secondary controls. The primary controls are the dynamic control loops that position the H_2 and O_2 flow control valves and the heat exchanger bypass valve used for propellant temperature control. The secondary controls are the logic circuitry required for system startup, shutdown, and monitoring.

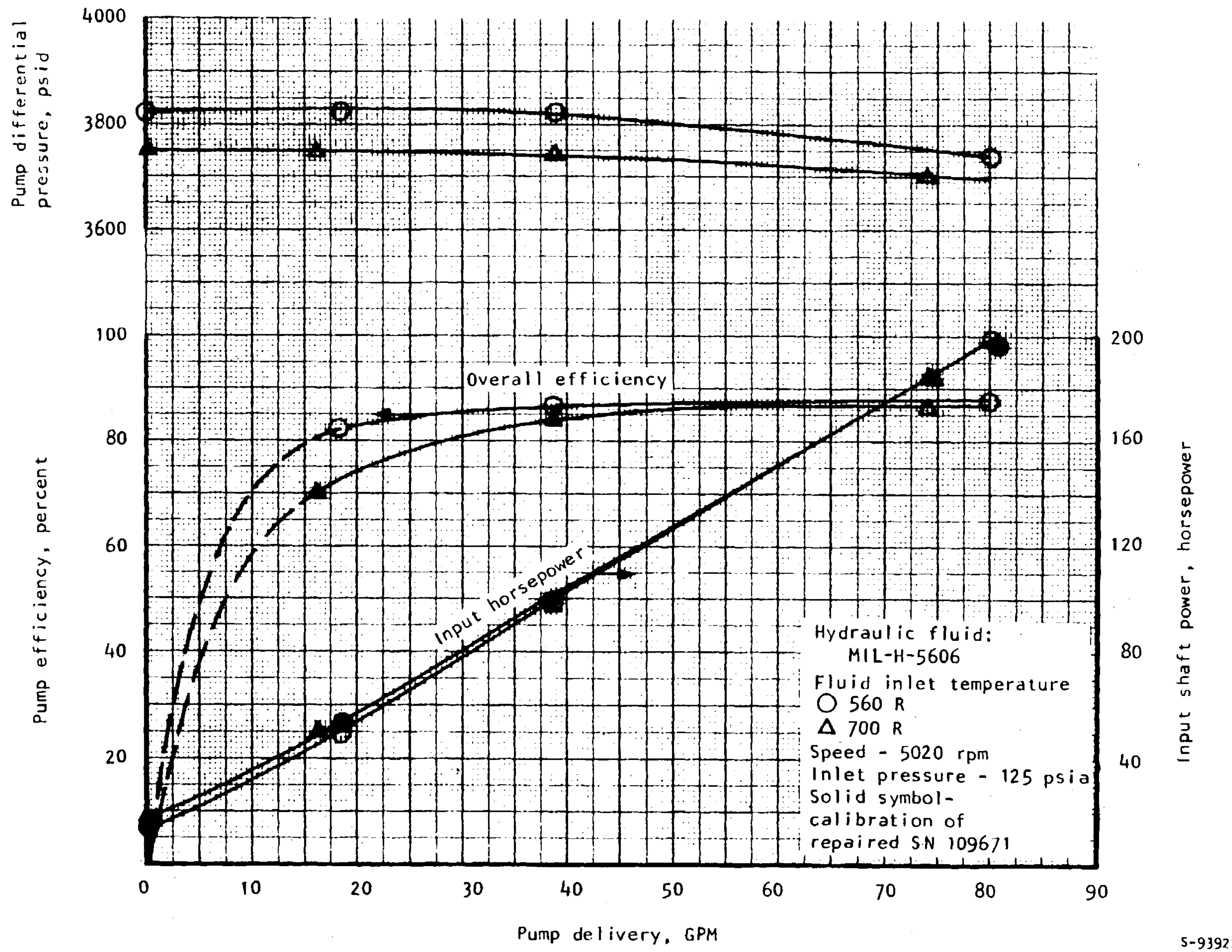

Figure 16.--Calibration of AP27V-3-02 Hydraulic Pump SN 109671.

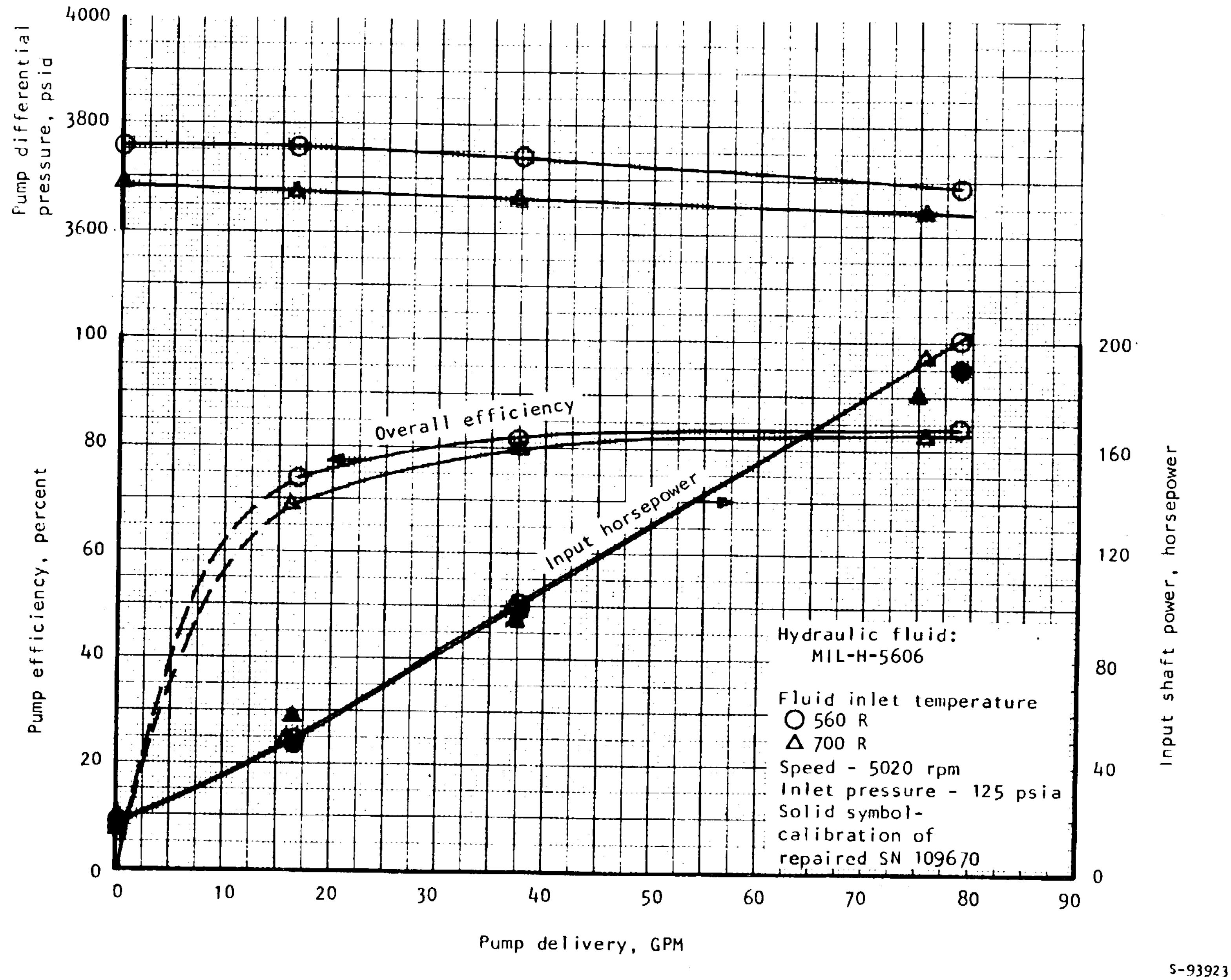

Figure 17.--Calibration of AP27V-3-02 Hydraulic Pump SN 109670.

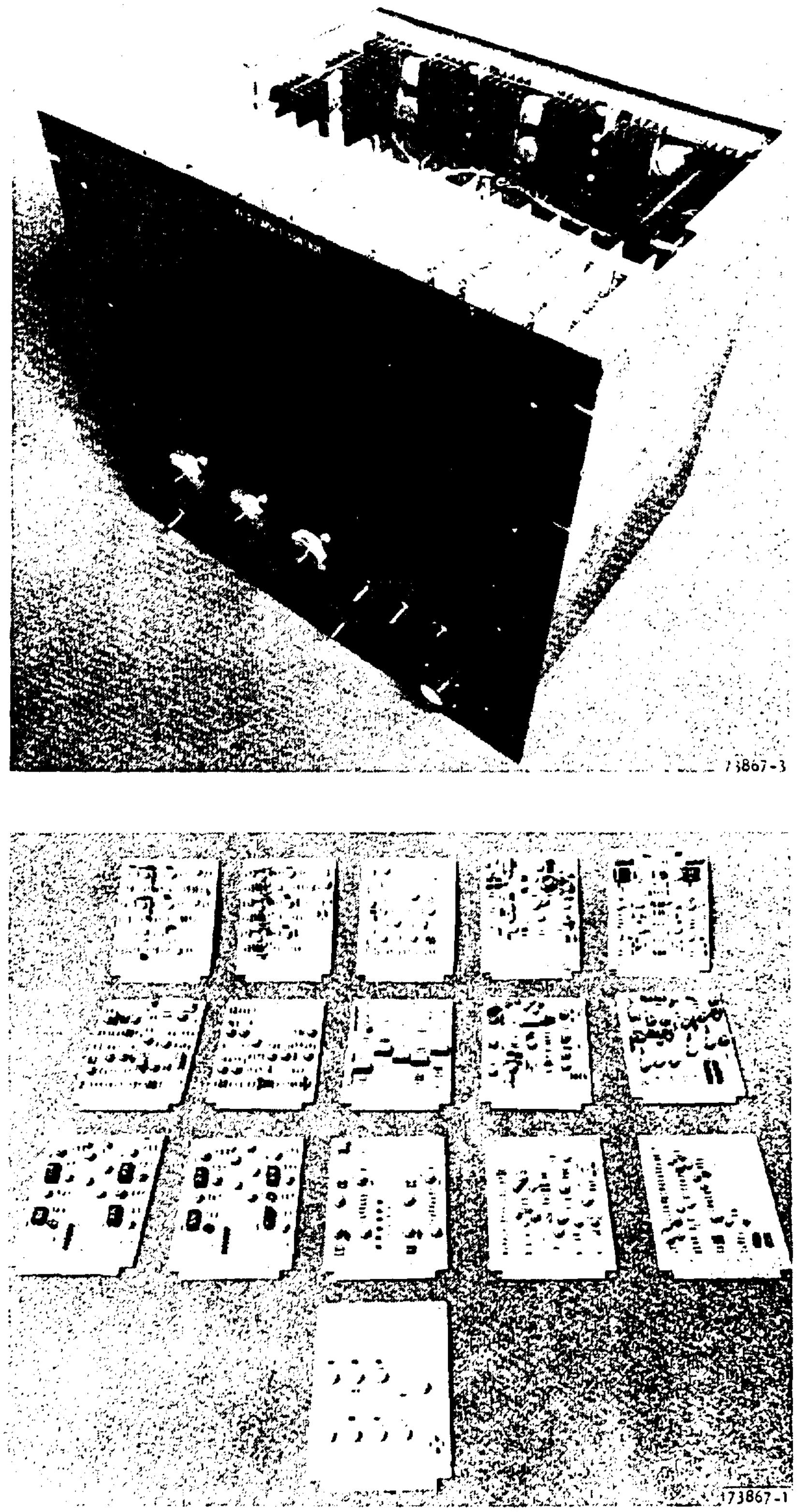

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Figure 18.--H_2-O_2 APU Electronic Control.

The breadboard control functions as a flight-type controller would, but contains certain features desirable for development that would not be incorporated into a flight design. For example, the combustor pressure and temperature, turbine speed, and equalizer outlet temperature can be adjusted to various set points other than the design values. With various set points there is great flexibility in initial testing. A number of the automatic fail-safe shutdown provisions are included only for development of the APU. Details of the control subsystem design can be found in ref. 1. The control concept was verified prior to system tests using a turbine simulator (analog). Test results are summarized in Appendix A, Control Subsystem Tests, and the testing resulted in a subsystem capable of controlling the APU-T system.

Primary controls.--The primary controls, shown in fig. 19, include the following:

(1) Turbine speed control

(2) Turbine temperature control

(3) Bypass controls

The logic of each of these controls is shown in the applicable partitions of the block diagram (fig. 19). In operation, the turbine speed control compares actual turbine speed with a reference speed, either 20 000 or 63 000 rpm. The 20 000-rpm reference speed allows slow speed operation of the APU during initial checkout and the 63 000-rpm reference speed provides the primary control during normal operation. The turbine inlet temperature control is cross-coupled with the turbine speed control and controls the ratio of oxygen valve area to hydrogen valve area. A speed change commands the hydrogen and oxygen valves to move together, either both open or both closed, to maintain a constant temperature in the combustor. At the same time, mass flow through the combustor is controlled to provide the required APU power requirements of the turbine. The bypass controls are cross-coupled with the control of the hydrogen temperature to the inlet of both the hydraulic oil cooler and combustor. With this network, bypass flows can be adjusted to prevent freezing either hydraulic oil or lube oil.

Turbine speed control: The speed control is an integral control that is compensated with various dynamic terms. The forward transfer function (fig. 19) is the integrating control portion of the controller. The output of this block comes into the lowest wins (that is, only the lowest value of several outputs is used in the next control segment), which is compared with the power demand out of the pressure control loop. A pressure control enables open loop operation of the turbine by controlling combustor pressure. A variable reference from 100 to 500 psig slowly accelerates the turbine to avoid overspeed. The pressure control is a straight integral control loop. A reference pressure of 500 psig is above maximum attainable combustor pressure. This moves the pressure control loop into a regime where it does not affect the subsystem control. In a production H_2-O_2 APU, the pressure control loop would not be necessary.

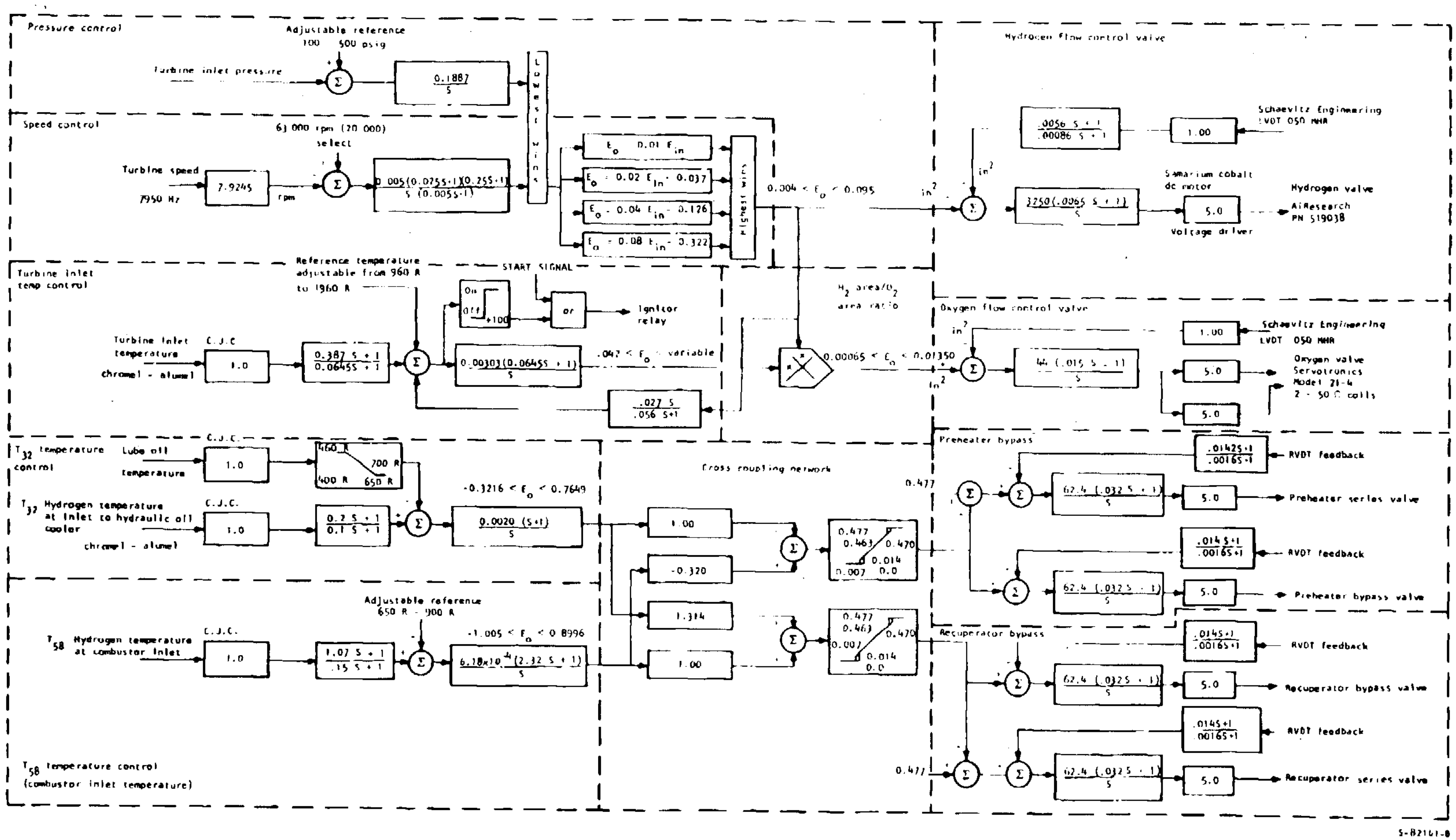

Figure 19.--H_2-O_2 Space Shuttle APU Primary Controls

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The output of the lowest wins is fed into a four-segment function generator which is used to increase the gain of the loop as the control valve goes from choked to subsonic flow. This allows the overall loop gain to remain approximately constant throughout the operating range of the APU. The output of the function generator then feeds directly into the hydrogen flow control valve minor loop. The minor loop is a positioning loop on the control valve enabling faster total response for small control valve signals than would otherwise be possible. Therefore, the speed control primarily opens or closes the hydrogen valve according to whether the speed is too high or too low. It also cross-couples into the turbine inlet temperature control, which is also an integral control.

Turbine inlet temperature control: The turbine inlet temperature control is coupled with the speed control to maintain a constant temperature in the combustor for various turbine power requirements. That is, with a change in the position of the hydrogen flow control valve (as determined by the speed control), the position of the oxygen flow control valve is changed simultaneously to maintain essentially the same valve area ratio during the initial part of the transient. Oxygen valve position subsequently is trimmed by the turbine inlet temperature control as required. The oxygen flow control valve has a positioning loop to provide faster closed loop response with small variations and control position. In this way, close temperature control can be maintained during a load transient using a temperature sensor with relatively slow response. At the same time, the accuracy of a closed-loop control is obtained for steady-state operation at any load condition essentially independent of ambient conditions or propellant inlet temperature.

The control loop uses a lead-lag network in the feedback to compensate for the slow response of the thermocouple and to provide stability for the temperature control loop. The thermocouple is undercompensated at minimum power, which results in a controlled gas temperature that is high when the temperature of the thermocouple is low. As the thermocouple approaches steady state, the gas temperature also approaches steady state. The opposite occurs at maximum power; a low thermocouple temperature results in low gas temperature.

Bypass controls: The bypass controls are separate from the turbine speed and turbine inlet temperature controls. They consist of the T-32 temperature control and the T-58 temperature control, which are, respectively, the control of the hydrogen temperature at the inlet of the hydraulic oil cooler and the control of the hydrogen temperature as it enters the combustor. Both control loops are integral control loops with lead-lag feedback to compensate for the time constants in the thermocouples and the output of the two integrators that are fed into a cross-coupling network. There is a nondynamic cross-coupling of the bypass and series valves to provide a minimum interaction between the control loops at the expected crossover frequencies.

The cross-coupling network is designed so that the T-32 temperature control can fully open or fully close the preheater bypass valve, independently of the T-58 temperature control output setting. Conversely, the combustor control can fully open or fully close the recuperator bypass valve independently of the output of the hydraulic oil control integrator. Both of these control loops are cross-coupled to provide an overall system that separates the variables. When the preheater bypass valve is repositioned, it not only changes the temperature coming out of the preheater, and thus the temperature coming into the hydraulic oil heat exchanger, but also the amount of temperature drop that the hydrogen receives between the recuperator and the equalizer; therefore, it affects the combustor inlet temperature. The same is true of the recuperator bypass. To decrease the amount of bypass around the recuperator, the hydrogen temperature increases at the mixing point to raise the temperature going into the preheater as well as into the equalizer and finally into the combustor.

The cross-coupling network thus handles the requirement of two temperature controls and takes into account the interaction of both temperatures with a change in either of the bypass valves. Both valves move in such a way that the hydraulic oil inlet temperature is not affected by changes in the output of the combustor inlet temperature control.

Secondary controls.--The startup and shutdown logic shown in fig. 20 is designed primarily to prevent an oxygen-rich mixture from passing over the hot turbomachinery. This requires that the hydrogen shutoff valve open first. After the hydrogen pressure is obtained and hydrogen flow is established, the oxygen valve is opened.

For shutdown, the oxygen shutoff valve is closed. The signal that closes the oxygen shutoff valve also reduces the command of the combustor pressure control to 50 psig. Interruption of the oxygen flow is detected by the turbine inlet temperature sensor, and the hydrogen shutoff valve remains open until the temperature of the overtemperature thermocouple is below 900 R; 900 R is used because the turbine inlet temperature control point can be selected as low as 960 R.

The startup and shutdown logic incorporates several subsystem interlocking features and receives several monitoring inputs which assure a safe, smooth start with minimal temperature perturbations at the combustor and the turbine.

If at startup all monitoring conditions are valid (no failures within the system) and the startup switch is turned on, the hydrogen shutoff valve is opened and hydrogen flows into the hydrogen side of the propellant conditioning system. When the hydrogen pressure reaches 300 psig, a hydrogen underpressure switch (located after the equalizer and before the hydrogen flow control valve) is closed, which allows the oxygen shutoff valve to sequence open.

As this secondary control imposes the proper startup sequence, the primary control opens the hydrogen flow control valve fully to bring the turbine up to speed. At the same time, the turbine inlet temperature is below operating temperature, which would normally open the oxygen flow control valve fully. However, to avoid overtemperature of the combustor at startup, the turbine inlet temperature control at the output of the integrator is limited in range to a 4-percent minimum and a variable maximum, which limits the oxygen flow control valve area to 4 percent of the hydrogen flow control valve area as long as the oxygen shutoff valve is closed. That is, when the oxygen shutoff valve is closed, both the minimum and maximum limit ratios are 4 percent, but when the oxygen shutoff valve is open, the upper limit on the ratio increases exponentially to 22 percent. Exponential increase of the maximum limit ratio slowly increases the flow to the combustor and allows the sensing

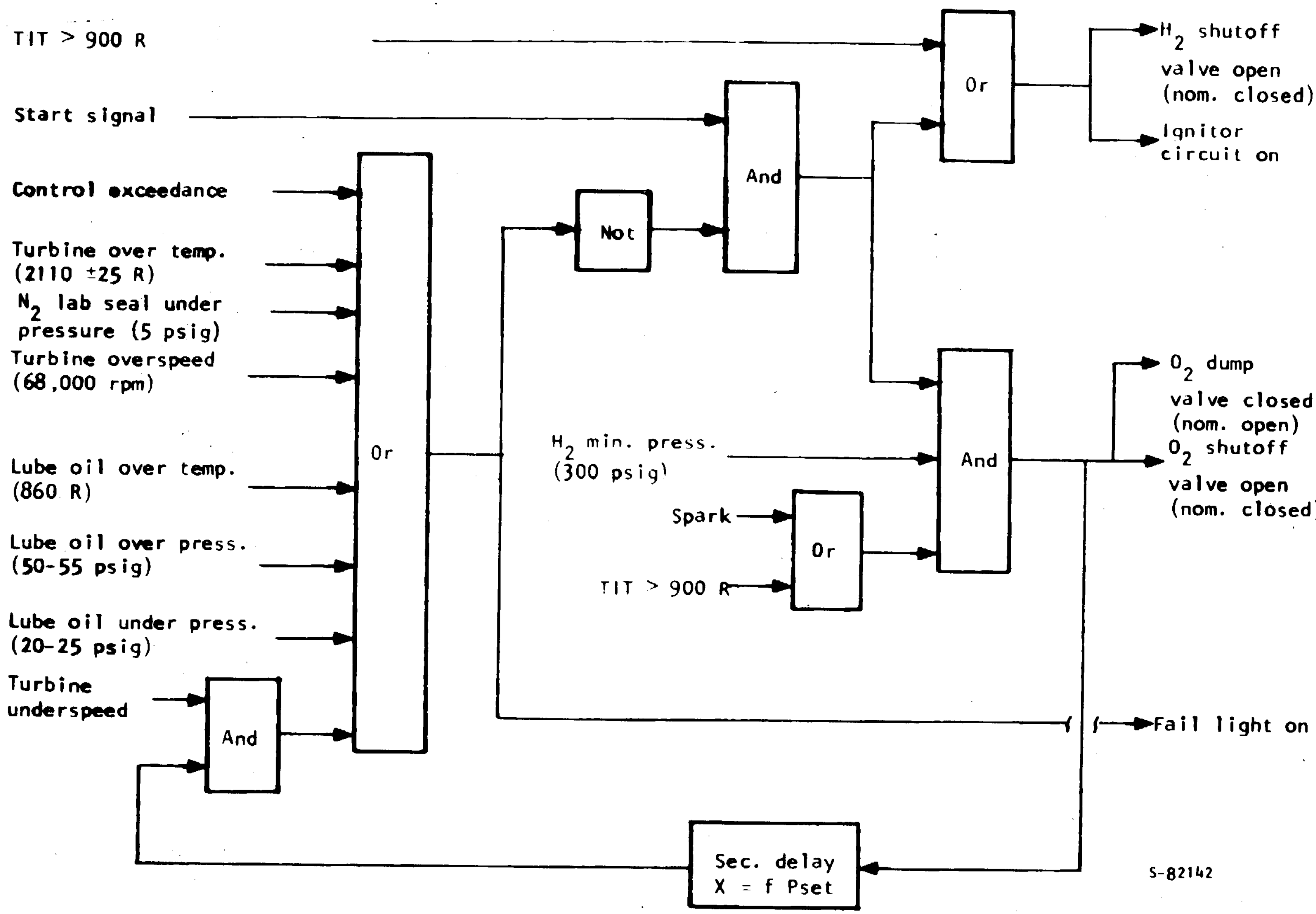
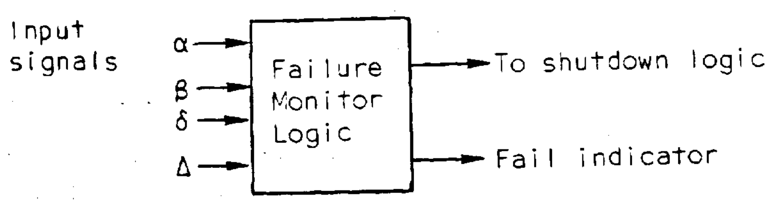


Figure 20.--H_2-O_2 APU Startup and Shutdown Control Logic.

thermocouple to reach the control point before an overtemperature occurs in the combustor. As the combustor temperature comes up to the control point, the temperature control automatically takes over and slowly overrides the maximum limit ratio. If a failure is detected or the start switch is turned off, the valves close in an opposite sequence. First, the oxygen shutoff valve closes. As the temperature drops in the combustor, the temperature control loop opens the oxygen flow control valve, but the valve is pulled back to the minimum position because the oxygen shutoff valve has been closed. Also, in response to the drop in combustion temperature, the hydrogen flow control valve starts to open to maintain turbine speed, but when temperature in the combustor drops below 900 R, a timer is started for the hydrogen shutoff valve. After 15 sec, the hydrogen shutoff valve is closed. At that time, the hydrogen flow control valve will start to open, trying to maintain the turbine speed. It will continue to open until it reaches the full open point, at which time the turbine speed will actually decrease and the turbine then will start its deceleration. The 15-sec delay before the hydrogen shutoff valve is closed permits hydrogen flow to cool down the combustor and the turbine area. It was found during testing, however, that with cryogenic propellant, this cooling down period affected the APU adversely and should be eliminated with no cooldown period prior to valve closure.

Monitor: The monitor philosophy of the APU system is to monitor selected parameters and to initiate a normal shutdown upon detection of possible failure. The parameters were selected by weighing two factors: (1) the criticality of the parameter, and (2) the ease of obtaining the data. Special sensors were incorporated into the system to obtain independent measurement of the turbine speed and the turbine inlet temperature. The difference in turbine inlet temperature as measured by the two thermocouples is accomplished by the incorporation of an amplifier and two diodes. The approach has been to set the failure limits conservatively with the hazard of unnecessary shutdowns. That is, the system is shut down, and then the problem is determined. The limits for shutdown are shown in fig. 20. If one of the monitored parameters consistently shuts down the system, the parameter limit can be changed or the monitoring of that particular point can be deleted.

Monitoring functions: A block diagram of the failure monitoring is shown below.



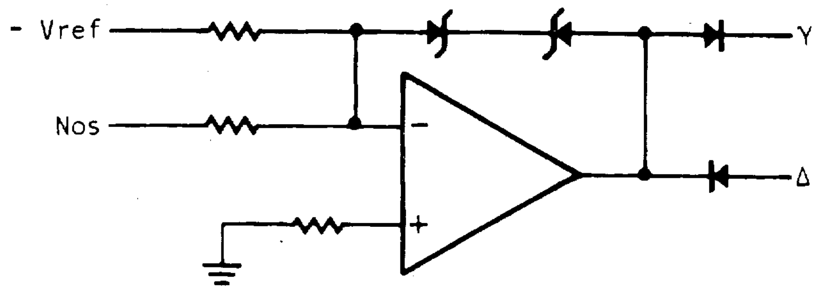
The four input signals are defined as α, β, δ, and Δ. The nonfailure logic levels are defined as:

$$\alpha \le 1.0 \qquad \delta \le 8.0$$

$$\beta \ge -8.0 \qquad \Delta \ge -1.0$$

If any or all of these logic levels are exceeded for a period of 0.02 sec, two logic signals are provided: one to energize the failure indicator and the other as a signal to the shutdown logic.

The control system was mechanized with the control circuits scaled electrically so that their dynamic operating range did not exceed the failure monitor voltage limits. In cases where this was not possible, the circuits were bounded to predetermined maximum amplitudes with low leakage zener diodes. An example of this type of circuit is shown below.



The failure monitor continuously monitors the input parameters for continuity and level exceedance. Some of the monitored parameters are the turbine speed monopoles, all thermocouple inputs, and loss of position feedback signals.

Sensors: The three types of sensors used to provide information to the controller are (1) speed, (2) temperature, and (3) pressure.

Two speed sensors are used. The first counts the passage of the 95 teeth of the pump drive gear, which rotates at 5020 rpm, and provides a nominal 7948-Hz signal to the controller for the primary speed control. A second identical sensor is located so that it counts a 60-tooth disk on the turbine shaft. It provides a nominal 63 000-Hz signal that is used to detect an overspeed condition.

Four thermocouples are used to monitor gas temperatures in the system. These thermocouples are of a special design to combine high response with resistance to the effects of hot hydrogen gas and a vibratory environment. The thermocouple joint is supported in a magnesium oxide insulation swaged in an 0.032-in.-dia Inconel tube. This design provides a time constant of approximately 0.2 to 0.4 sec, depending on the gas flow rates.

Two pressure switches are used to provide a switched signal to the controller in the event of overpressure or underpressure in the lubrication system. An overpressure condition could occur if the oil in the oil cooler congealed sufficiently to block the flow. The underpressure switch checks if lube oil is flowing.

An additional pressure switch detects hydrogen underpressure. When the hydrogen pressure reaches 300 psig, the switch is closed allowing the oxygen shutoff valve to sequence open.

Valves: The APU-T system valves include eight valves in the following four configurations:

(1) Four identical hydrogen bypass valves

(2) Two identical oxygen pressure regulators

(3) A hydrogen flow control valve

(4) An oxygen flow control valve

All but the oxygen regulators are controlled by electrical signals from the APU-T controller. The valves were designed to conform to reference system specifications as a minimum, but are not flight weight.

Oxygen pressure regulator: The oxygen regulator (fig. 21) function is to regulate oxygen pressure at the inlet to the combustor.

In the oxygen pressure regulator, a ceramic ball-poppet valve is positioned by a calibration spring and differential pressure acting on a bellows actuator.

The regulator normally is full-open. As downstream pressure reaches the regulation band, the downstream pressure, which is vented to one side of the bellows actuator, overcomes an opposing load due to the calibration spring plus ambient pressure acting on the other side of the actuator. The actuator moves and allows a spring to move the ball poppet toward the closed position. The balance of forces--downstream pressure on one side of the actuator and the calibration spring and ambient pressure on the other--maintains the poppet position required for regulation.

A port is provided on the top of the valve body for connecting the regulator to ambient. If oxygen internal leakage should occur, it would be ducted overboard (to ambient).

Two identical regulators are connected in series, with the downstream regulator set 50 psi higher than the other. The downstream unit, therefore, protects against an open failure of the prime unit without interfering with normal regulation.

Performance characteristics are as follows:

Working fluid	GO_2
Regulated outlet pressure, psig	550 ± 25
Maximum flow, lb/min (ref)	6.62
Inlet pressure, psia	878
Temperature, R	663
Pressure drop, psid	313

Minimum flow, lb/min (ref)	0.454
Inlet pressure, psia	900
Temperature, R	750
Pressure drop, psid	335
Response time	100 ms from min. to max.
Life	1000 hr

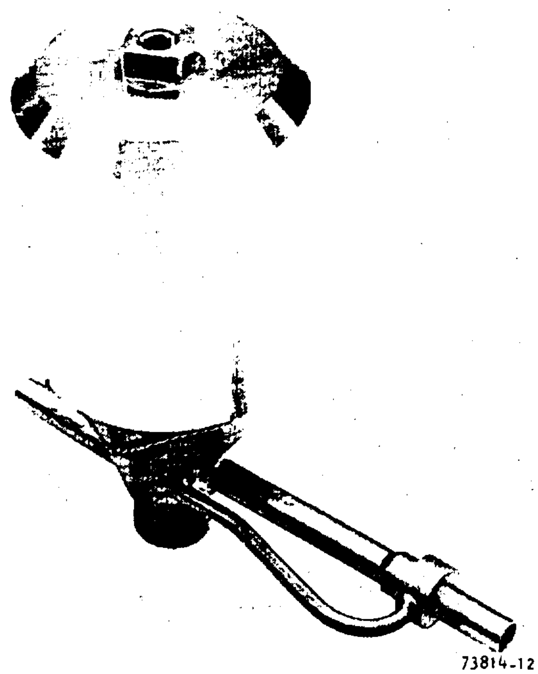


Figure 21.--Oxygen Pressure Regulator.

Hydrogen bypass valve: The four identical hydrogen bypass valves (fig. 22) in the system operate in response to electrical drive signals from the system controller. Two of the valves control bypass flow around the recuperator, and two of the valves control bypass flow around the preheater. The bypass flow around these two heat exchangers is varied as required to control hydrogen temperature at the combustor inlet and at the inlets to the hydraulic and lube oil coolers.

The valve modulates hydrogen flow by rotation of a circular flat plate in the flow duct. The plate is attached to a shaft that is connected to the torque motor. Application of current to the torque motor causes the valve to move toward open. With increasing current, the valve will continue to open, with the travel limited to 80 deg by a mechanical stop. In the closed position, the valve does not seal leak-tight.

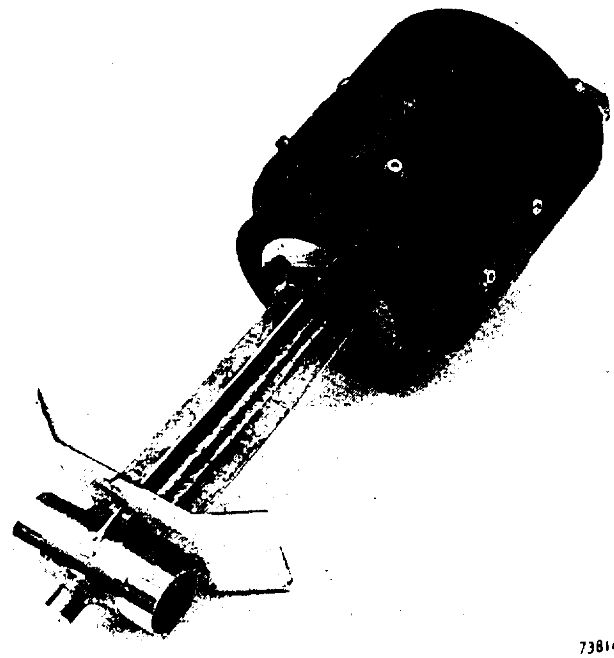


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Figure 22.--Hydrogen Bypass Valve.

In the current APU-T, two valves are used for each of the heat exchanger bypass circuits: one in series with the heat exchanger and one in parallel. As one valve opens, the other closes. The two valves in each bypass loop are linked electronically so they act like a three-way valve. The two valve sets are also electronically coupled in the control to prevent undesirable interaction. In a flight-type design, each pair of valves would be replaced by a three-way modulating valve.

Performance characteristics are as follows:

Working fluid	GH_2
Maximum flow, lb/min	7.83
Inlet pressure, psia	541
Temperature, R	520
Pressure drop, psid	0.8
Minimum flow, lb/min	0.0288
Inlet pressure, psia	563
Temperature, R	550

Pressure drop, psid	0.6
LVDT resolution	$\pm$0.5 percent of full scale
Response time	200 ms from min.-to-max.

Oxygen flow control valve: This valve (fig. 23) modulates oxygen flow to the combustor in response to electrical control signals and maintains turbine inlet temperature constant with varying load and system conditions.

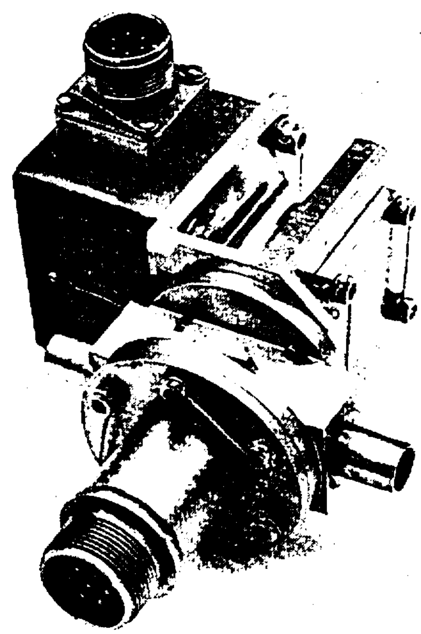

Figure 23.--Oxygen Control Valve.

The basic components of the oxygen flow control valve are: (1) a dual-poppet assembly, (2) a dc, dry-type, linear displacement torque motor (Servotronics Part Number 99-D0201), and (3) an LVDT (Schaevitz Engineering Type 050 MHR).

Electrical input signals from the control are fed to the torque motor, which is directly coupled to the dual poppet valve shaft. As torque motor current is increased from zero, the spring-loaded-closed poppet assembly is displaced off its stop. This admits gaseous oxygen into the combustor. Gas flow increases as current is increased until the flow reaches a maximum value at the full open position of the dual poppets.

Poppet arrangement on a common shaft provides pressure force balancing to minimize power requirements of the actuating torque motor. Because of this balance effect, the torque motor output directly drives the poppet assembly.

Poppet position is fed back to the control circuitry by means of a 400-Hz LVDT. The LVDT case is attached to the valve case, and the movable core is threaded to the poppet shaft. The position of the poppet thus is registered within the control logic for control monitoring.

The torque motor assumes the closed valve position with zero electrical current input. An additional magnetic closing force exists at the zero current conditions. The separate poppet closing spring acts to force the poppets closed. Thus, the oxygen control valve has redundant forces in the closing position in the event of power loss.

The performance characteristics are as follows:

Working fluid	GO_2
Maximum flow, lb/min (reference)	6.62
Inlet pressure, psia	532
Temperature, R	663
Pressure drop, psid	61.8
Minimum flow, lb/min (reference)	0.454
Inlet pressure, psia	570
Temperature, R	750
Pressure drop, psid	536
Pressure out, psia	34
LVDT resolution	$\pm$0.5 percent of full scale
Response time	40 ms from min.-to-max. condition
Life	1000 hr

Hydrogen flow control valve: The hydrogen control valve modulates hydrogen flow to the combustor in response to electrical control signals, and maintains constant turbine speed under varying APU loads and system conditions.

The basic components of the hydrogen flow control valve are: (1) a dual-poppet assembly, (2) a samarium cobalt dc motor (AiResearch PN 519038), and (3) a linear variable displacement transformer (LVDT) (Schaevitz Engineering Type 050 MHR). The valve has been designed to meet the requirements of the hydrogen flow control valve specification. The control valve was originally designed with a torque motor, but the motor was undersized, and as a result, the torque tube was subjected to high loads and was subject to cracking. The development testing which led to the use of an electric motor drive can be found in Appendix A, Control Subsystem Tests. The electric motor-driven hydrogen control valve (fig. 24) includes a slip clutch to prevent excessive loads to the drive and a return spring which opens the valve upon loss of electrical power.

Electrical input signals from the control are applied to the electric motor drive, which is connected to one end of a pivoted lever. The opposite end of the lever is attached to the poppet valve shaft on which dual poppets are mounted.

The normal (deenergized) position of the electric motor output shaft is held at the midstroke position of the motor by a return spring. This position corresponds to the midstroke of the poppet valves. Upon application of polarized current (corresponding to a close-valve signal) to the electric motor drive, the valve poppets are forced against the poppet spring toward the closed position. As current is increased, poppet movement continues until the poppet shaft is against a mechanical stop (valve nearly closed). As current is decreased, the valve moves back toward the central position. A change in electric motor polarity drives the poppets toward the full-open position. This motion is assisted by the poppet spring.

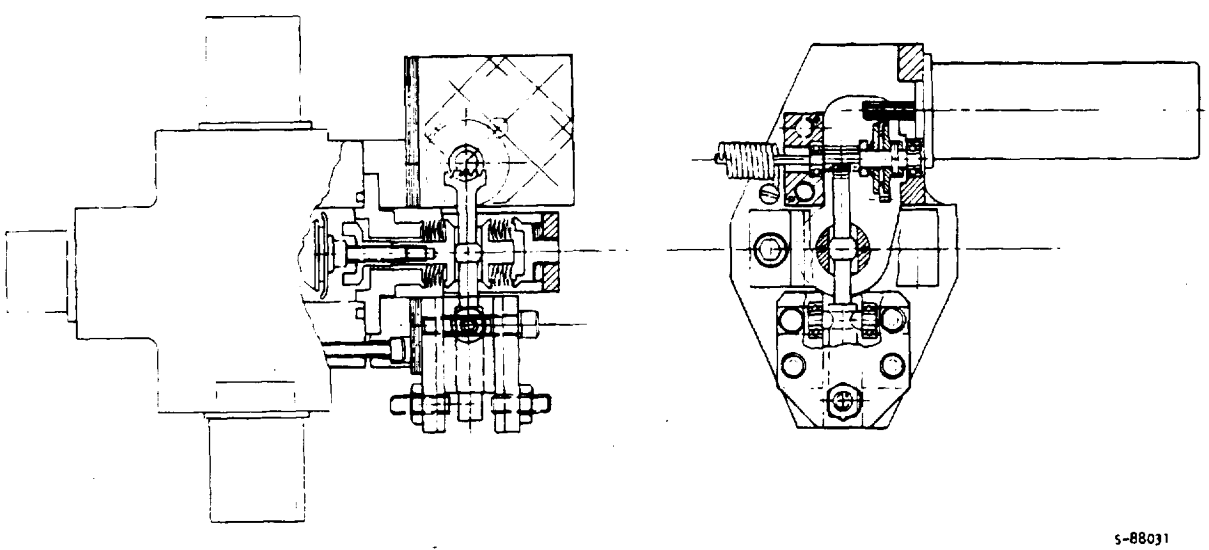

Figure 24.--Layout Electric Motor-Driven H_2 Flow Valve.

Poppet position is fed back to the control circuitry by means of a 400-Hz LVDT. The LVDT case is attached to the valve case and the movable core is threaded to the poppet shaft. The position of the poppet thus is registered within the control logic for control monitoring.

Performance characteristics are as follows:

Working fluid	GH_2
Maximum flow, lb/min (reference)	9.02
Inlet pressure, psia	506
Temperature, R	693
Pressure drop, psid	45.3
CA (reference), in.^{2}	0.0950
Minimum flow, lb/min (reference)	0.701
Inlet pressure, psia	575
Temperature, R	750
Pressure drop, psid	540
CA (reference), in.^{2}	0.00400
LVDT resolution	$\pm$0.5 percent of full scale
Response time	40 ms from min.-to-max. condition
Life	1000 hr

APU-T SYSTEM TESTS

Test Purpose and Data Obtained

The APU-T is an experimental test version of the APU system described in the previous two sections. The system was designed to investigate and demonstrate the new technology required for the flight-type APU. The specific test purposes were as follows:

(1) Develop and verify the operation of the control subsystem.

(2) Develop and verify proper functioning of the various components in the system environment.

(3) Determine the performance and operating characteristics of the overall system and system components under various transient and steady-state load conditions.

(4) Develop and verify the validity of the computer simulator model.

Data were taken to determine the flow pressure and temperature entering and leaving each process. Performance was calculated from digital data. Operating characteristics were determined from digital data and oscillograph traces at selected stations where transients were of interest. Overall performance was calculated from hydraulic and propellant flow measurements. Turbine shaft power was calculated using hydraulic pump calibrations performed by the pump manufacturer.

Test Facility Description

Testing of the APU-T system was accomplished at the AiResearch Mint Canyon facility in the layout shown in fig. 25. Photographs and schematics of the APU-T system as it was installed in the facility are given in figs. 26 through 32. System components are listed in table 7. As reflected in the schematics, the APU-T test system comprises the reactant circuits (fig. 27), reactant thermal conditioning circuit (fig. 28), exhaust ejector system (fig. 28), power unit circuit (fig. 29), the hydraulic load bank circuit (fig. 30), the ignition system (fig. 31), the controller (fig. 32), and the data acquistion system. In all significant aspects, these circuits are identical with those described for the reference system. Descriptions supplementing those of the reference system follow.

Reactant circuit.--The reactant circuit is shown schematically in fig. 27. As shown in the figure, the circuit includes gaseous hydrogen and oxygen supplies, and liquid nitrogen and hydrogen supplies. In operation, the hydrogen tank was filled from a 2500-psig tank trailer furnished by the hydrogen supplier. When LH_2 operation was required, the gas from the hydrogen tank, regulated to 560 psig, was cooled to LH_2 temperatures (typically 50 R). Cooling of the flow was accomplished in two heat exchangers: the flow was precooled by LN_2 in the first exchanger and finally cooled to LH_2 temperature by LH_2 in the second.

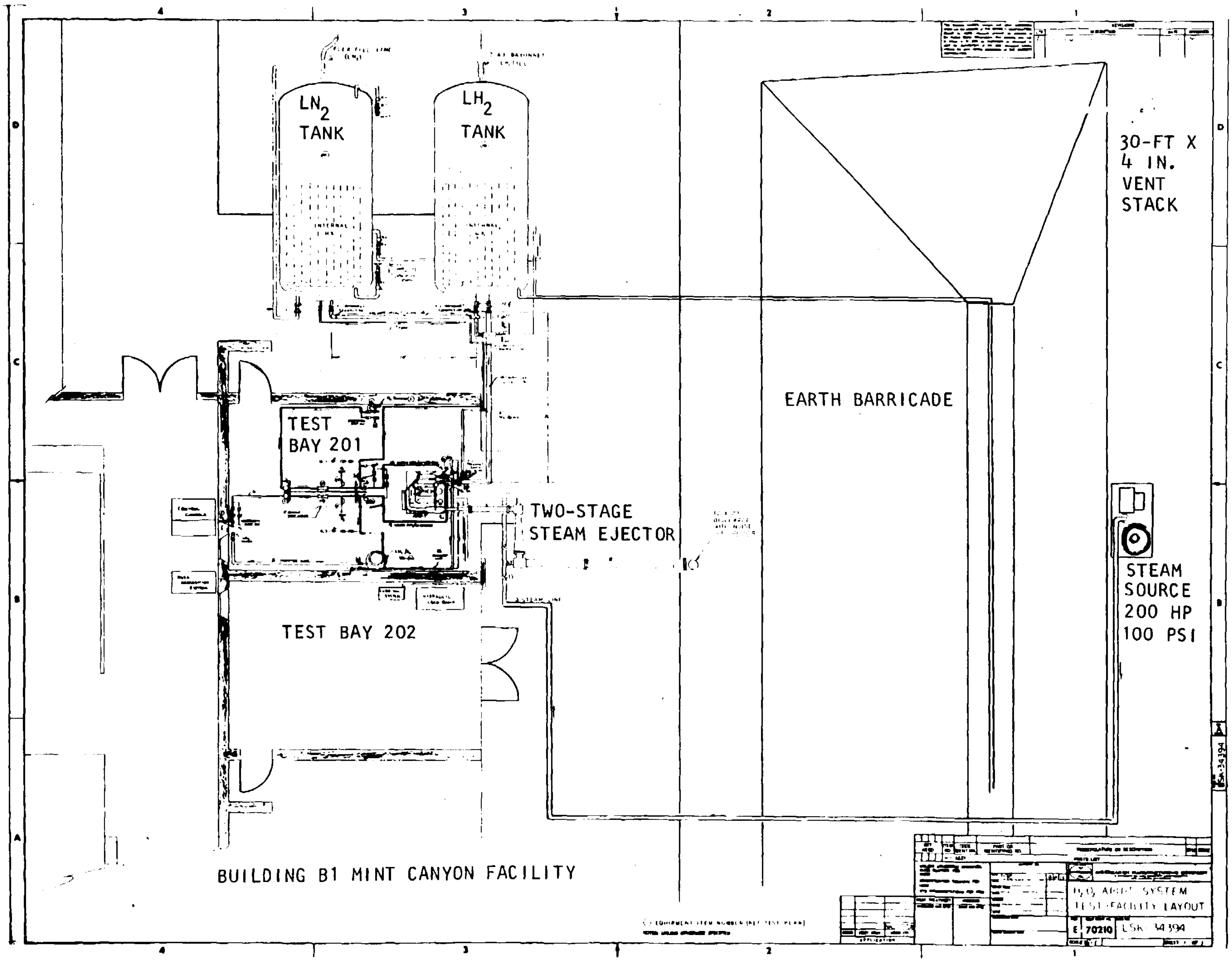

Figure 25.--APU-1 Facility Layout.

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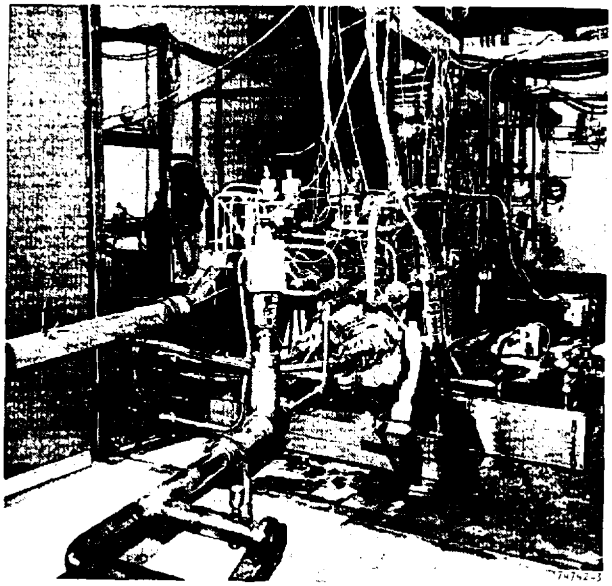
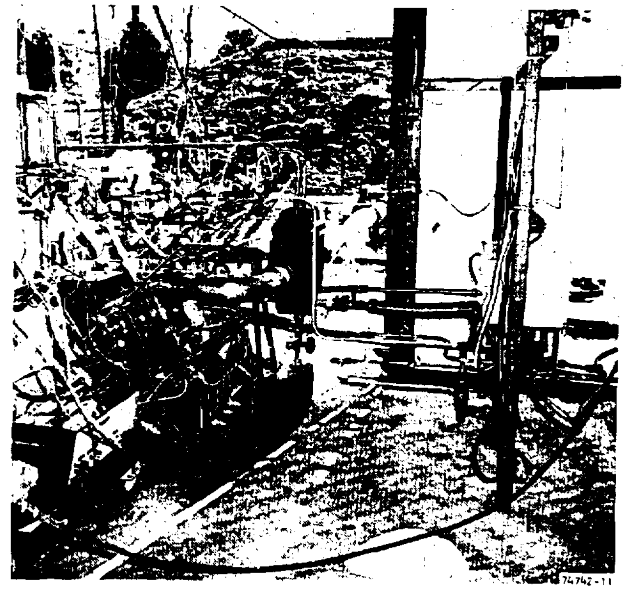
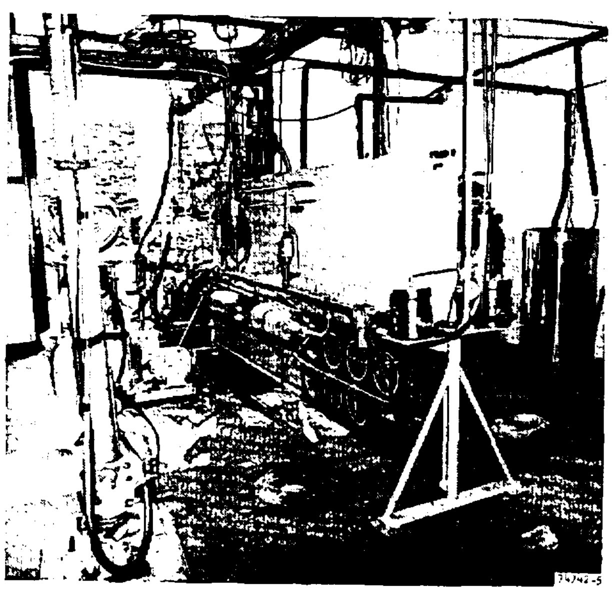


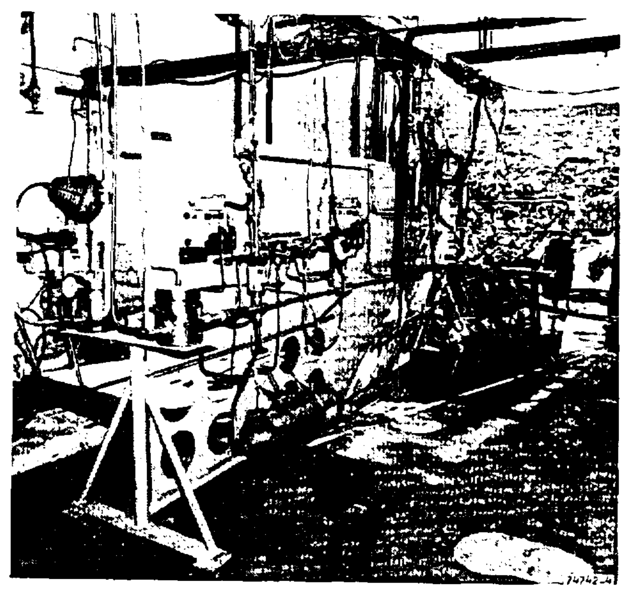
View of hydraulic pumps in the test setup



View of recuperator and exhaust in test setup



View of hydrogen supply to APU-T



View of oxygen supply to APU-T

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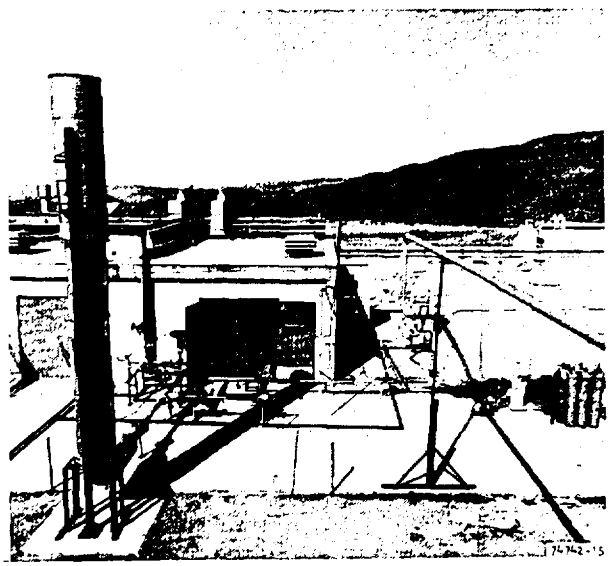
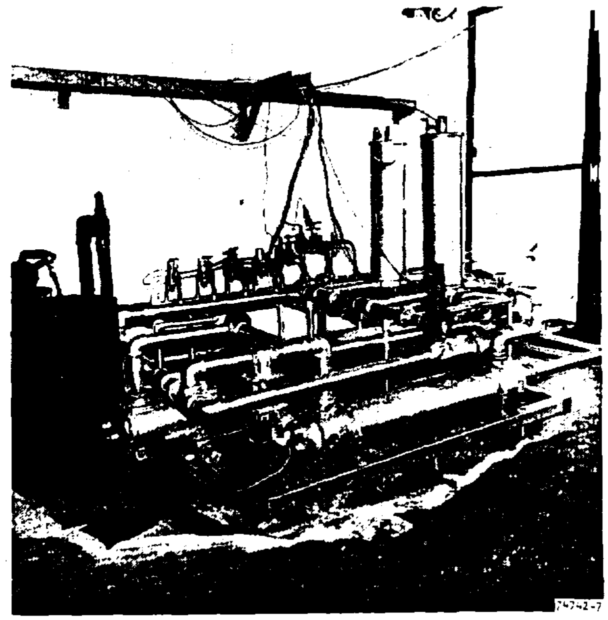
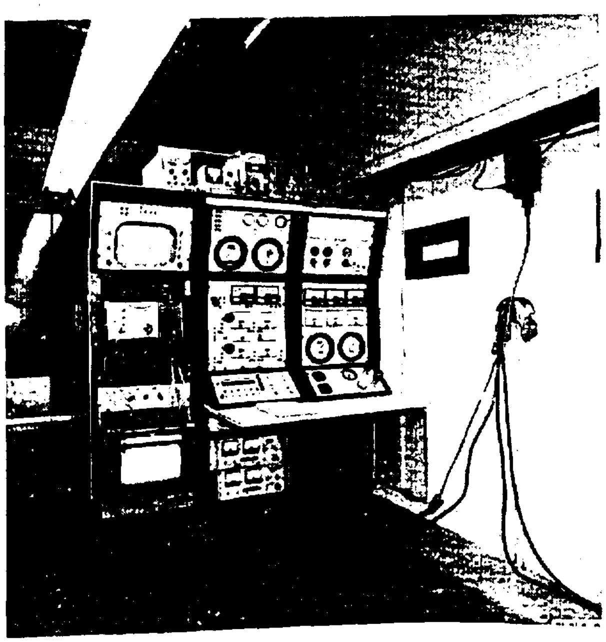
Figure 26.--APU-T System Installed In Test Facility.



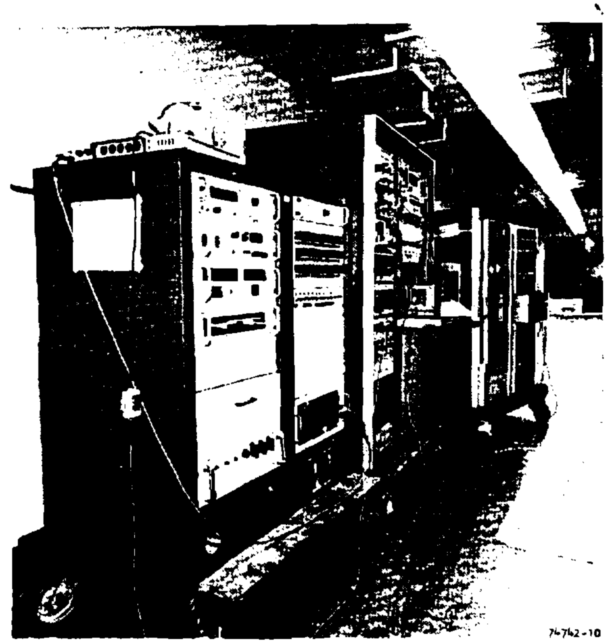
View of test cell and LH_2 and LN_2 tanks



Hydraulic load bank



Control console and electronic control



Digital and analog data acquisition equipment

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Figure 26.--APU-T System Installed in Test Facility (Continued).

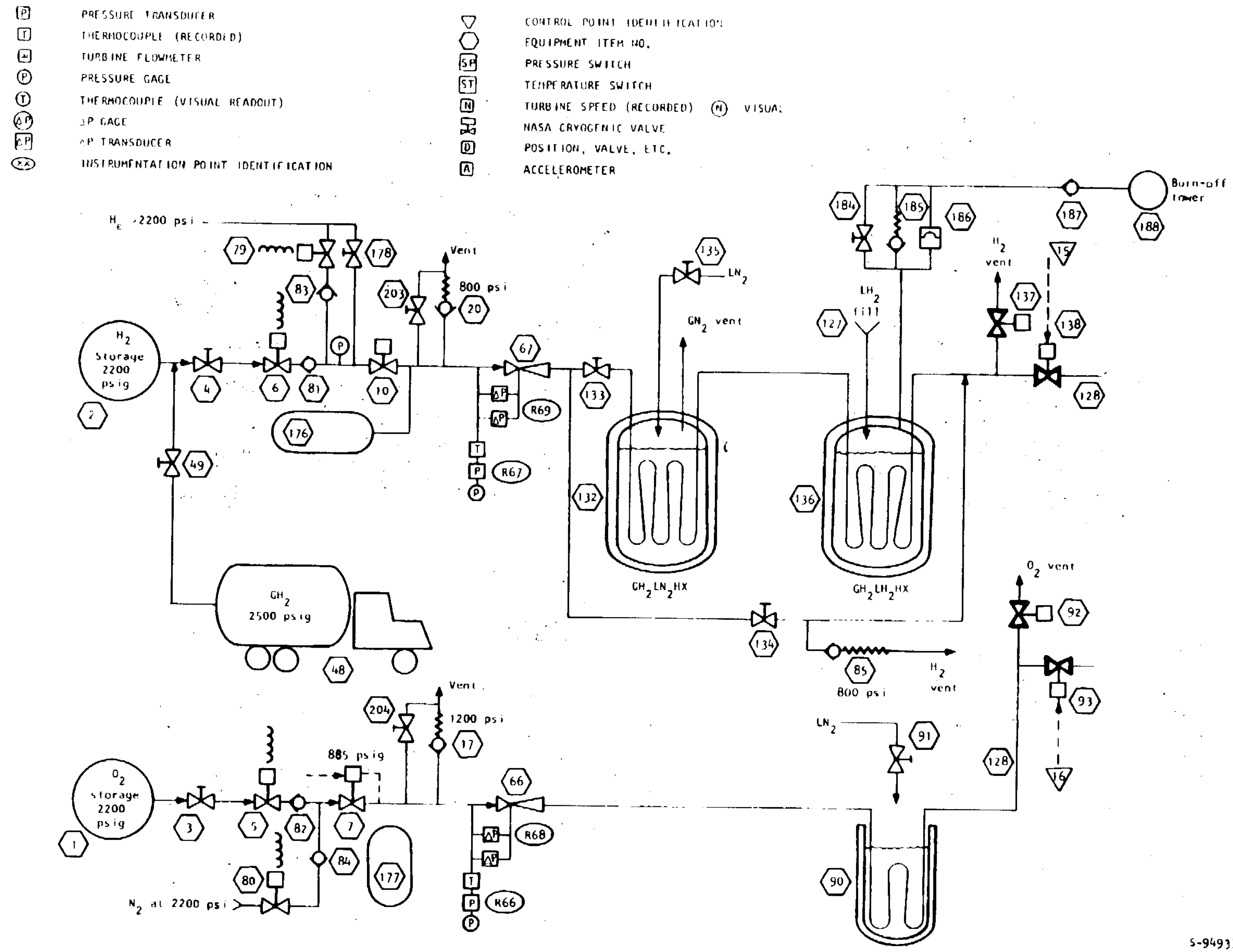

Figure 27.--System Tests, Reactant Circuits (Showing Instrumentation Points).

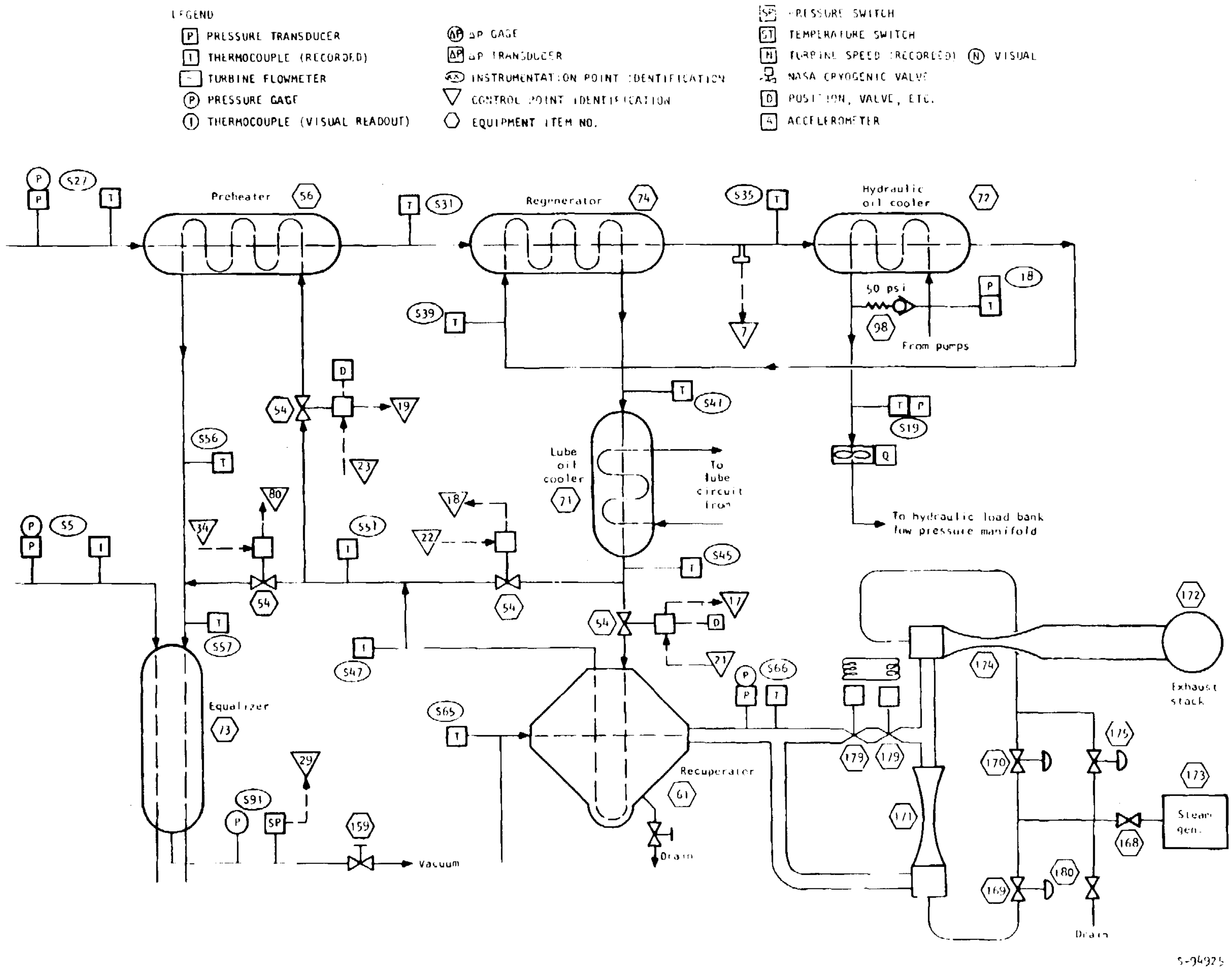

Figure 28.--System Tests, Reactant Thermal Conditioning Circuits and Steam Ejector System (Showing Instrumentation Points).

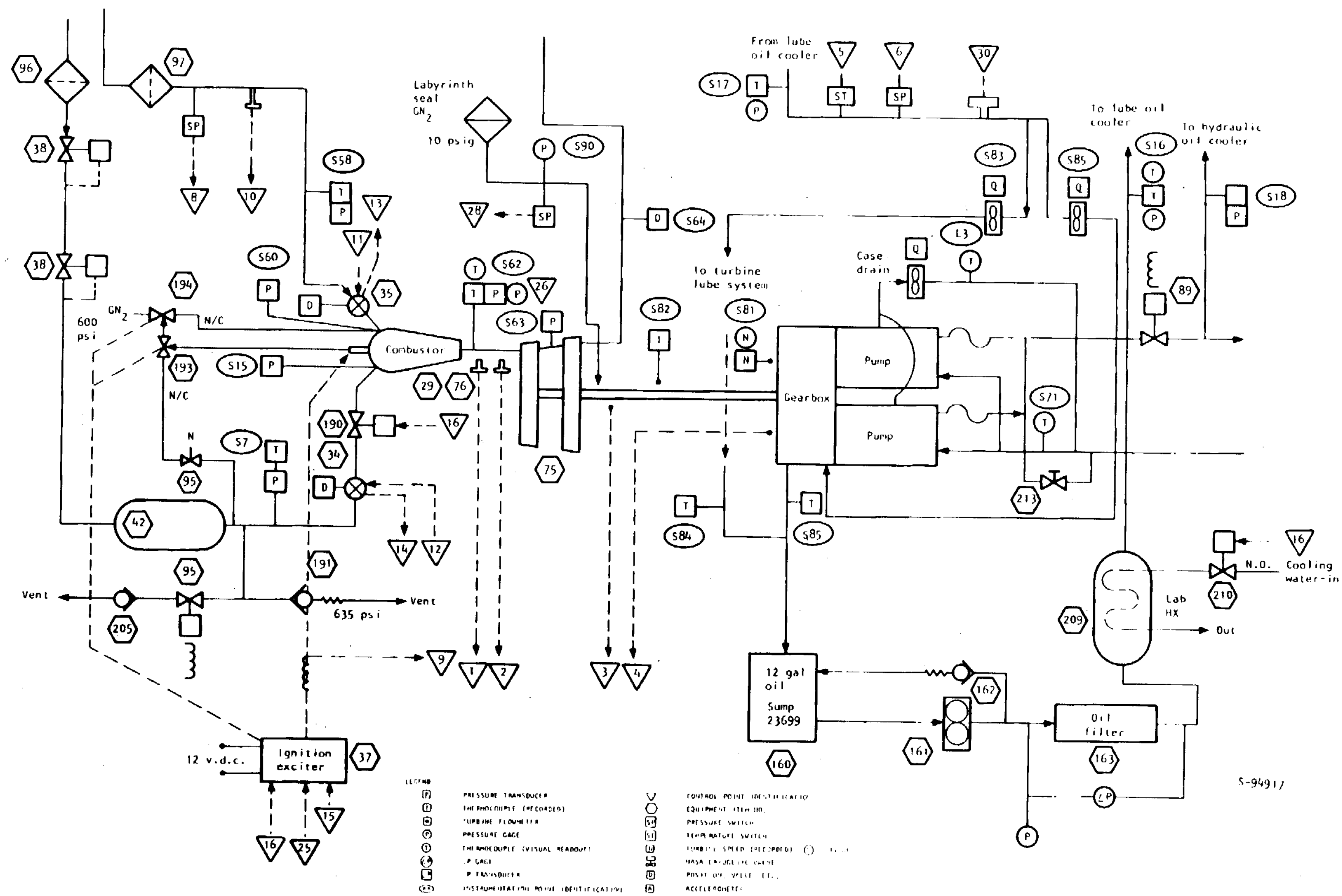

Figure 29.--Systems Test, Power Unit Circuits (Showing Instrumentation Points).

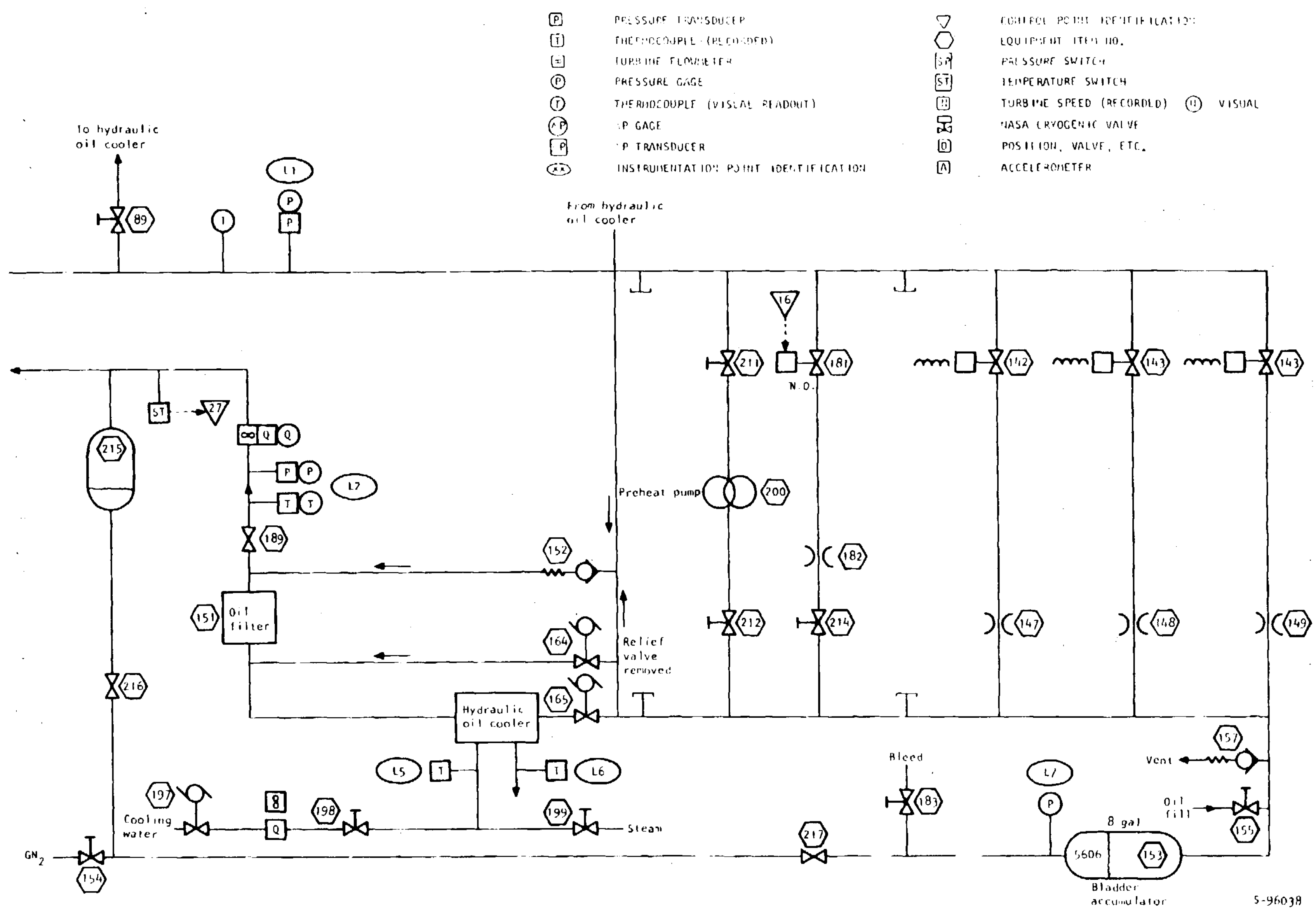

Figure 30.--System Tests, Hydraulic Load Bank Circuits (Showing Instrumentation Points).

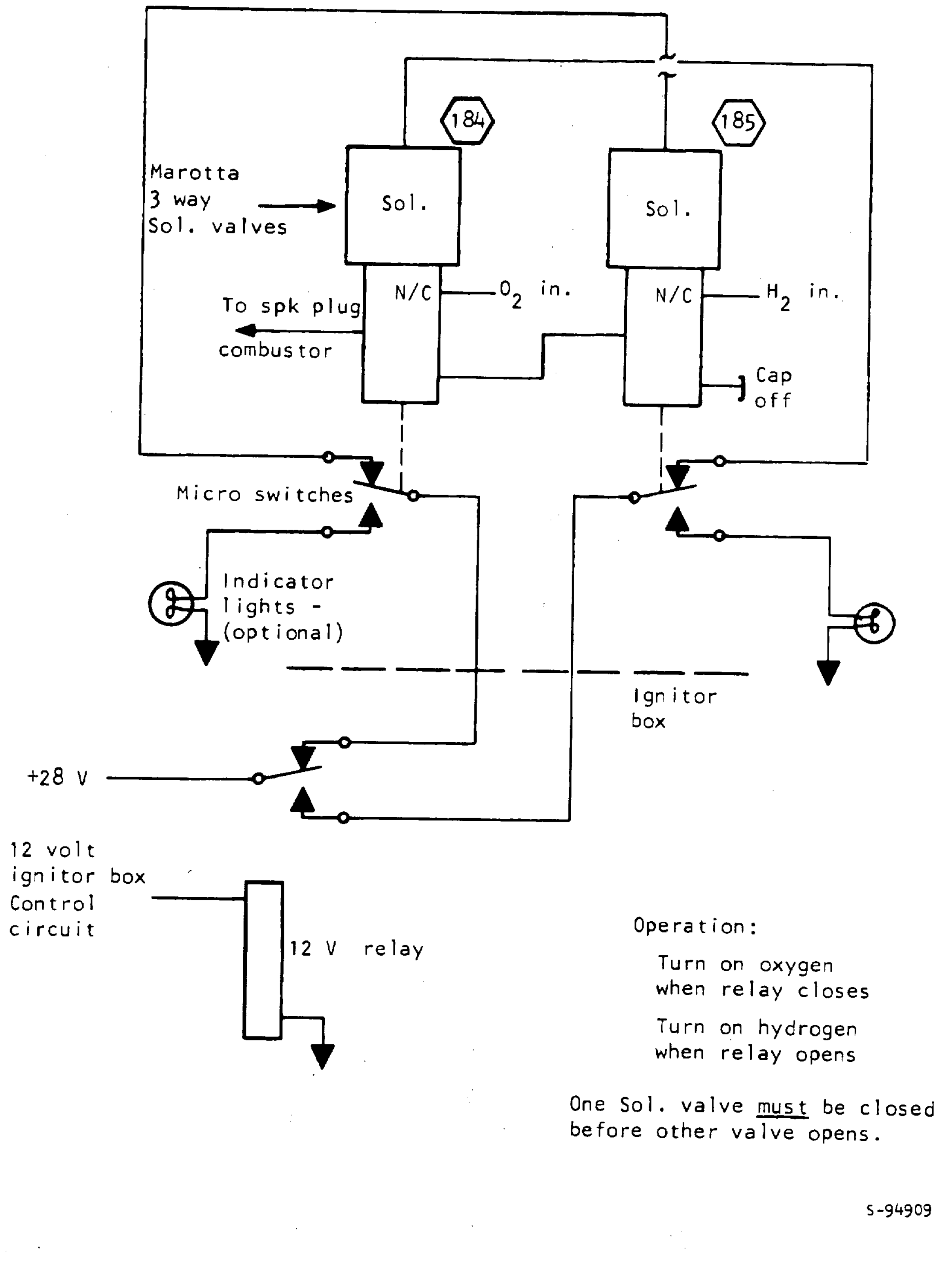

Figure 31.--Spark Plug Gas Supply Circuit Schematic.

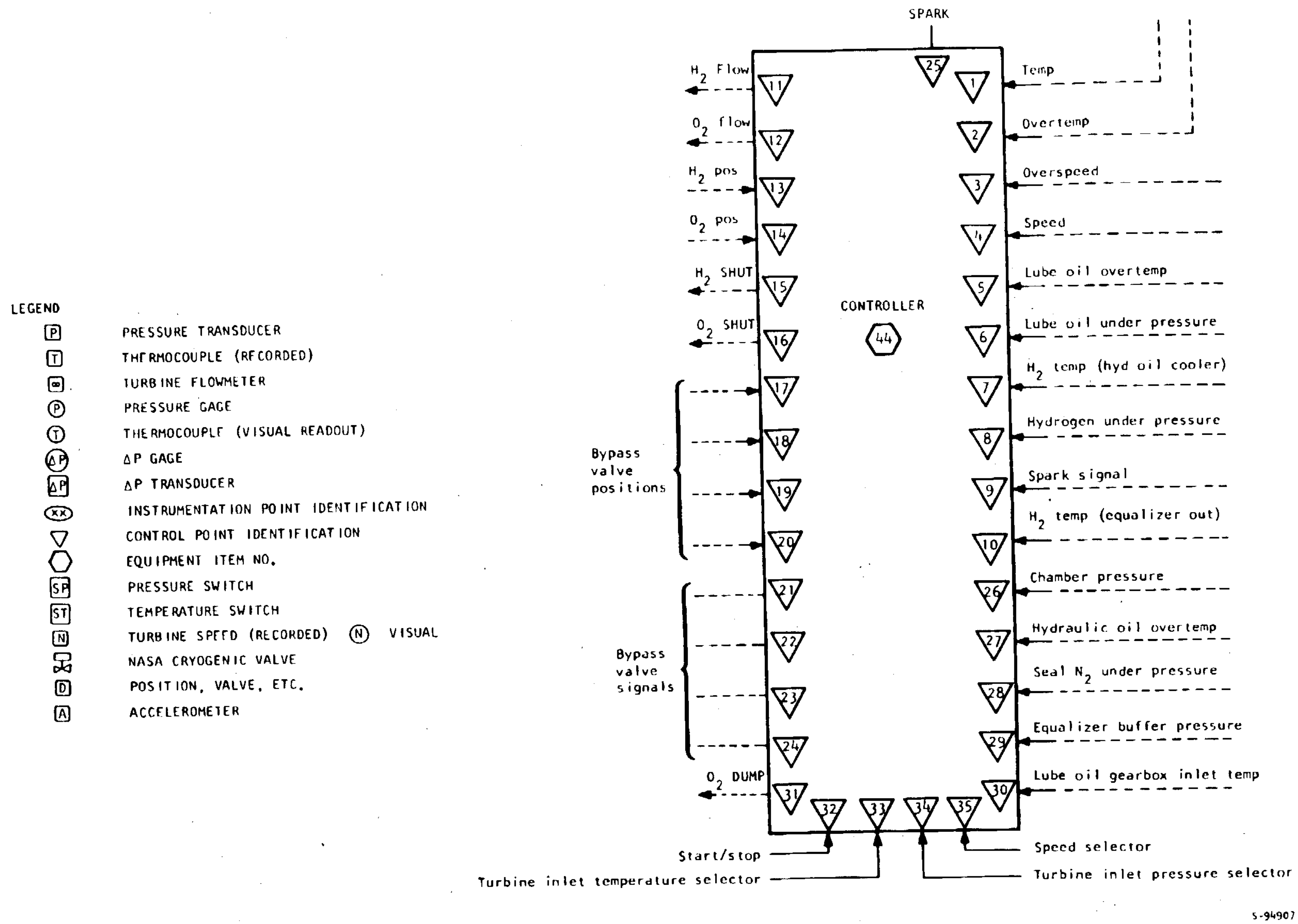

Figure 32.--System Tests, Controller (Showing Instrumentation Points).

TABLE 7

EQUIPMENT LIST

Item	Name	Description
1	O_2 storage tank	
2	H_2 storage tank	
3	O_2 shutoff	Manual
4	H_2 shutoff	Manual
5	O_2 shutoff	Remote
6	H_2 shutoff	Remote
7	O_2 regulator	
10	H_2 regulator	
17	O_2 relief valve	
20	H_2 relief valve	
29	Combustor head	PN SK65202
34	O_2 control valve	PN 394372
35	H_2 control valve	PN 394376-1
37	Ignition exciter	
38	O_2 regulator	PN 393154 (2 required)
42	O_2 accumulator	PN
44	APU-T controller	PN
45	Turbine analog	PN
46	Hydraulic load selector	(Part of analog)
48	H_2 truck	
49	H_2 truck shutoff	
54	Bypass valve	PN 394376-1 (4 required)
56	Preheater	PN 159170-1
61	Recuperator	PN 159560-1
63	O_2/LN_2 heat exchanger	
64	O_2/LN_2 heat exchanger shutoff valve	
65	O_2/LN_2 heat exchanger bypass valve	
66	O_2 venturi	NASA V5
67	H_2 venturi	NASA V6
71	Lubricating oil cooler	PN 159550-1
72	Hydraulic oil cooler	PN 159550-1
73	Equalizer	PN 159580-1
74	Regenerator	PN 159570-1
75	Turbine power unit	PN 581190-1
76	Thermocouple, control	PN DSW-787 (2 required)
77	Oxygen check valve	PN 3C2148 (crissaire)
78	Flywheel	DSW-788
79	Purge valve (H_2 side)	
80	Purge valve (O_2 side)	
81	Check valve (H_2 line)	
82	Check valve (O_2 line)	
83	Check valve (H_2 purge)	
84	Check valve (O_2 purge)	
85	Relief valve, H_2	
86	Case drain return valve	8 gpm (N.O.)
87	Case drain to cooler valve	8 gpm (N.O.)
88	Oil cooler flow valve	8 gpm (N.O.)
89	Oil cooler meter valve	Needle valve (8 gpm)
90	GO_2-LN_2 heat exchanger	Existing dewar
91	LN_2 fill valve	On test cell wall
92	GO_2 vent valve	NASA
93	GO_2 shutoff valve	NASA
94	O_2 dump valve	
95	O_2 dump valve (lab oper)	
96	O_2 filter	
97	H_2 filter	
98	LH_2-hydraulic oil heat exchanger bypass	8 gpm at 0°F
99	Hydraulic pump shutoff valve	
101[a]	LH_2 pump inlet shutoff	
102[a]	LH_2 tank fill shutoff	
103[a]	LH_2 pump outlet valve	
104[a]	LH_2 pump	
105[a]	LH_2 tank vent valve	
106[a]	LH_2 tank pressure control	
107[a]	LH_2 tank safety disc	
108[a]	LH_2 tank relief valve	
109[a]	H_2 vent stack	
110[a]	LH_2 pump relief	
111[a]	LH_2 pump safety disc	
112[a]	LH_2 tank pressure control	
113[a]	N_2 regulator	
114[a]	N_2 regulator	
115[a]	LH_2 tank pressure shutoff	
116[a]	N_2 shutoff	
117[a]	LH_2 tank	NASA CE 53489 75 cu ft
118[a]	Vacuum pump	
119[a]	Vacuum jacket burst disc	
127[a]	LH_2 fill connection	
128	Vacuum jacketed line	
129[a]	LH_2 pump childown valve	
130[a]	Childown pilot valve	
131	N_2 regulator	
132	GH_2LN_2 heat exchanger	
133	GH_2LN_2 shutoff valve	
134	GH_2LN_2 bypass valve	
135	GH_2LN_2 fill valve	
136	GH_2LH_2 heat exchanger	
137	GH_2 vent valve	NASA
138	GH_2 shutoff valve	NASA
141	Hydraulic load valve	
142	Hydraulic load valve	
143	Hydraulic load valve	
144	Hydraulic load orifice	gpm at 3000 Δpsi
145	Hydraulic load orifice	gpm at 3000 Δpsi
146	Hydraulic load orifice	gpm at 3000 Δpsi
147	Hydraulic load orifice	gpm at 3000 Δpsi
148	Hydraulic load orifice	gpm at 3000 Δpsi
149	Hydraulic load orifice	gpm at 3000 Δpsi
150	Hydraulic oil/water heat exchanger	
151	Hydraulic oil filter	
152	Hydraulic oil filter bypass	
153	Pressurized reservoir	
154	N_2 fill valve	
155	Oil fill valve	
156	Vacuum vent valve	
157	Low-pressure relief valve	
158	High-pressure relief valve	
159	Equalizer vacuum valve	
160	Lubricating oil sump	
161	Lubricating pump	gpm
162	Lubricating relief valve	45 Δpsi
163	Lubricating oil filter	
164	Hydraulic oil/H_2O heat exchanger bypass valve	
165	Hydraulic oil/H_2O heat exchanger series valve	
166	Lubricating oil pressure mode valve	
167	Lubricating scavenge pump	
168	Ejector control valve	
169	Steam shutoff 1st stage	
170	Steam shutoff 2nd stage	
171	Steam ejector	
172	Exhaust stack	
173	Steam plant	

All numbers from 1 to 175 were used; omissions indicate inactive numbers.
[a] LH_2 system not used.

When checkout on GH_2 was required, the heat exchangers were bypassed. Flow measurement was accomplished with a metering venturi located upstream of the heat exchangers and the bypass.

Reactant thermal conditioning circuit.--From the reactant circuits, the propellant entered the reactant thermal conditioning circuit (shown in fig. 28) where the various heat transfer functions were performed to heat the cryogenic temperature propellants to a usable temperature and to cool the hydraulic and lube oil. This system is the same as that used in the APU reference system as described in detail under the headings: APU-T Propellant Feed and Conditioning Subsystem and Reference System.

Exhaust ejector system.--Space conditions were simulated in the turbine exhaust system and recuperator using a facility steam ejector. The ejector system circuit is included in fig. 28. A two-stage ejector was used with independent controls on each stage. This permitted the setting of exhaust pressure at the predicted value for space operation at any set of APU-T operating conditions. The system also was suitable for operation with ambient pressure exhaust.

Power units circuit.--The conditioned propellants entered the combustor and turbine through the H_2 and O_2 control valves, as shown in fig. 29. The power unit of the APU reference system is described in the sections entitled: APU-T Propellant Feed and Conditioning Subsystem and APU-T Turbopower Subsystem.

Hydraulic load bank circuits.--Operation of the APU-T at selected power levels was accomplished by imposing various hydraulic loads in the hydraulic load bank. To impose a given load flow, it was decided to use one of three branches in the hydraulic load bank by operating the appropriate solenoid bank from the control console. Flow rates corresponding to the selected power setting were preset using the hand-operated valve in the selected branch. Upon loss of electrical power to the controller, a 200-hp load would be applied to the turbine to prevent overspeed. A portion of the flow was hydrogen-cooled by the APU-T cooler to demonstrate the cooling function in the APU-T system. This flow included the pump case drain flow plus a portion of the pump discharge flow.

Cavitation of the pumps was prevented by holding their inlet pressure at 80 psig using a pressurized reservoir.

To simulate system operation on hot oil, the hydraulic oil was preheated to about 660 R prior to running the APU-T. Preheating was accomplished by introducing steam into the facility hydraulic oil cooler water, and circulating the oil through the cooler/heater with the preheat pump. After the oil reached the desired temperature, the steam supply and the circulating pump were shut down, and the test was started. During the test, further heating of the hydraulic oil occurred in the pumps. Oil temperature was manually controlled by varying the facility oil cooler water flow.

Ignition system.--Combustion was initiated by injecting ionized oxygen into the combustor using the modified automotive-type spark plug described in the previous section under the heading, Combustor. High voltage was supplied to the plug using an automotive-type electronic ignition system.

Spark was supplied to the combustor during startup only. Application of current to the plug was sensed in the controller by the use of an induction coil around the high-tension lead. Spark was supplied only when the H_2 control valve inlet pressure was above 300 psia and the turbine inlet temperature was below 1200 R. During this period, oxygen was supplied to the spark plug. When the spark was terminated, the oxygen flow was replaced by hydrogen to prevent breathing of combustor gases into the spark plug. A nitrogen purge was applied between the hydrogen and oxygen flows. The system providing these functions is defined in fig. 31.

Controller.--The electronic controller for the APU-T system is described in the previous section under the heading, APU-T control subsystem. The system is basically the same as that used for the reference system, except that certain features were added for development use. Options were provided in the controller so that turbine temperature and speed and hydrogen control valve inlet temperature could be selected by a dial setting. Also, a limit could be set on the combustor inlet pressure at any value between 100 and 400 psig. The controller inputs and outputs are given in fig. 32. The control instrumentation locations in the system are identified by flags that appear on the schematics of figs. 27 through 30.

Data acquisition.--The instrumentation data acquisition and reduction system consists of an acquisition subsystem located in the remote test facility at Mint Canyon and a data reduction subsystem located at both the Torrance and the Mint Canyon facilities. Transmission of raw data in digital format between the remote facility and the Torrance reduction facility is manual. A raw data tape and the appropriate test data sheet provide the input for the computer data reduction operation. The final output from the computer is available at the Torrance facility, which is in easy access to the engineering project groups requiring the reduced data. The data flow from this system is shown in fig. 33.

Data acquisition subsystem: Outputs of sensors located on both the test article and the support test equipment are signal-conditioned by the appropriate equipment located in the test control room. The ouput voltages from the signal conditioners (i.e., voltages proportional to the measured variable) provide the inputs to one or more of the three data recording systems according to the requirements listed in table 8. The recording systems are described below.

(1) Visual displays. The displays numerically provide those parameters that enable the test operator to ascertain the state of the test. The visual display also includes parameters not recorded on the data acquisition system. Such parameters are displayed using pressure gages, indicators, and other devices.

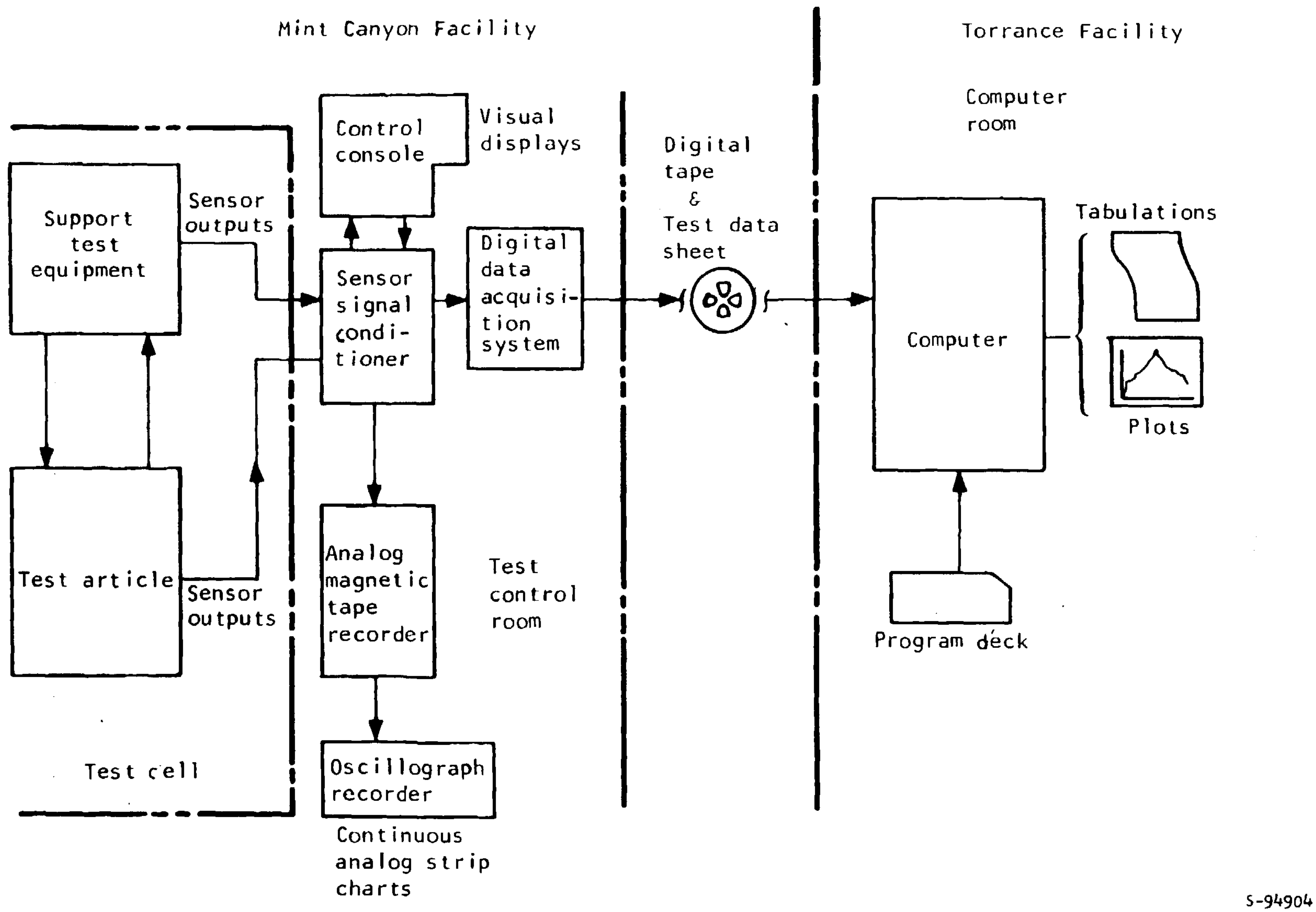

Figure 33.--Instrumentation Data Acquistion and Reduction.

TABLE 8

SUMMARY OF RECORDED DATA

Data Sta. No.	Fluid	Units	Max. Range	Oper. Range	Used In: Control System Test	Used In: Turbine/Gearbox Test	Used In: APU-T System Test	Recording Method: Digital Tape	Recording Method: Analog Tape	Recording Method: Visual	Recording Method: Strip Chart	Recording Method: Gage or Meter Ref Only		Instrumentation
RP66	GO_2	psig	0-1000	850-1000	+		x	+ x				x		Note 2
RT66	GO_2	°R	480-550	480-550	+		x	+ x						Note 3
RP68	GO_2	psig	0-1000	500-900	+		x	+ x						Note 2
RP67	GH_2	psig	0-800	600-800	+		x	+ x				x		Note 2
RT67	GH_2	°R	480-550	480-550	+		x	+ x						Note 3
RP69	GH_2	psig	0-800	300-600	+		x	+ x						Note 2
SP5	GO_2	psig	0-1000	850-950			x	x				x		Note 2
ST5	GO_2	°R	150-550	150-530			x	x						Note 4
SP7	GO_2	psig	0-1000	800-1000	+		x	+ x	+ x					Note 2
ST7	GO_2	°R	500-1000	700-950	+		x	+ x						Note 4
SP27	GH_2	psig	0-600	550-600			x	x				x		Note 2
ST27	GH_2	°R	40-500	40-550			x	x						Note 4
ST31	GH_2	°R	80-550	80-550			x	x						Note 4
ST35	GH_2	°R	400-700	400-700			x	x						Note 4
ST39	GH_2	°R	500-800	600-800			x	x						Note 4
ST41	GH_2	°R	400-800	400-800			x	x						Note 4
ST45	GH_2	°R	500-900	500-900			x	x					Hydrogen Circuit	Note 4
ST47	GH_2	°R	500-1500	800-1200			x	x						Note 4
ST51	GH_2	°R	500-1200	800-1200			x	x						Note 4
ST56	GH_2	°R	300-800	300-800			x	x						Note 4
SP58	GH_2	psig	0-600	500-600			x	x	x					Note 2
ST58	GH_2	°R	300-900	300-900			x	+ x	+ x					Note 4
SP62	$H_2 + H_2O$	psi	0-500	50-400	+		x	+ x	+ x			+ x		Note 2
ST62	$H_2 + H_2O$	°R	500-2100	1700-2100	+		x	+ x	+ x			+ x		Note 4
SP64	$H_2 + H_2O$	psig	-13 to +20	-13 to +20			x	x						Note 5
ST65	$H_2 + H_2O$	°R	500-1600	1200-1600			x	x					Turbine Out	Note 4
SP66	$H_2 + H_2O$	psig	-13 to +5	-13 to +5			x	x				x		Note 5
ST66	$H_2 + H_2O$	°R	500-1600	700-1600			x	x					System Out	Note 4
SN81	N.A.	Hz	0-8000	7000-8000	+o	o	x	+ x	+ x*	o		+ x	Turbine Speed	SK63258 (3 Req'd)
ST82	N.A.	°R	500-800	500-800		o			x		o	x	Turbine Bearing	Special T.C Install. (2)
ST57	H_2	°R	500-1000	500-1000			x	x					$-H_2$ Circuit	Note 4
SP60	H_2	psig	0-500	50-400	+				+					
SP75	O_2		0-500	50-400	+				+					
SP91	O_2, H_2	in. Hg Vac	0-30	0-30			x					x		
SP90	N_2	psig	0-10	4-7			x					x		

INSTRUMENTATION NOTES

1. For pressures 0 to 200 psig a Taber Model 217 or equivalent, pressure transducer will be used.
2. For higher pressures a Taber Model 206, or equivalent, will be used.
3. Std lab T/C.
4. LSK31931-8, or equivalent
5. For absolute pressures a Taber Series 254, or equivalent.

*Turbine analog output.

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TABLE 8.--Continued

Data Sta. No.	Fluid	Units	Max. Range	Oper. Range	Used In: Control System Test	Turbine/Gearbox Test	APU-T System Test	Recording Method: Digital Tape	Analog Tape	Visual	Strip Chart	Gage or Meter Ref Only		Instrumentation
LP1	Hyd Oil	psig	0-4000	3500-4000			x	x				x		Note 1
LP2	Hyd Oil	psig	0-200	50-150			x	x				x	Hydraulic Circuit	Note 2
LT2	Hyd Oil	$^{\circ}R$	400-800	400-750			x	x				x		Note 3
LQ2	Hyd Oil	gpm	0-200	0-170			x	x	x					Turbine Meter
LT5	Water	$^{\circ}R$	500-550	500-550			x	x						Note 3
LT6	Water	$^{\circ}R$	500-600	500-600			x	x					Hyd Ckt Water Cooler	Note 3
LQ6	Water	gpm					x	x						Turbine Meter
LP7	N_2	psig	0-200	50-100			x					x		Note 1
SD34	N.A.				+		x		+ x				Control Valve Positions	
SD35	N.A.				+		x		+ x					
SD54	N.A.						x		x				Bypass Valve Position	
SD54	N.A.						x							
SD54	N.A.						x		x					
SD54	N.A.						x	-						
ST18	Hyd Oil	$^{\circ}R$	500-760	500-760			x	x						Note 3
SP18	Hyd Oil	psi	0-200	50-150			x	x						Note 1
SP19	Hyd Oil	psi	0-100	50-100			x	x					Case Drain	Note 1
ST19	Hyd Oil	$^{\circ}R$	400-700	400-700			x	x						Note 3
SQ19	Hyd Oil	gpm	0-10	4-8			x	x						Turbine Meter
SD46	N.A.				+			+					Analog Hyd Input	
ST131	$H_2 + H_2O$	$^{\circ}R$	500-2200	1000-2200	+			+						
ST132	$H_2 + H_2O$	$^{\circ}R$	500-2200	1000-2200	+			+						
ST133	$H_2 + H_2O$	$^{\circ}R$	500-2200	1000-2200	+			+					Dummy Torus Nozzle Temp	
ST134	$H_2 + H_2O$	$^{\circ}R$	500-2200	1000-2200	+			+						
ST135	$H_2 + H_2O$	$^{\circ}R$	500-2200	1000-2200	+			+						
ST136	$H_2 + H_2O$	$^{\circ}R$	500-2200	1000-2200	+			+						
SQ83	Lube Oil	gpm	0-10	3-5		o	x	x		o				Turbine Meter
ST84	Lube Oil	$^{\circ}R$	500-850	500-850		o	x	x		o				Note 3
SQ85	Lube Oil	gpm	0-10	3-5		o	x	x		o				Turbine Meter
ST86	Lube Oil	$^{\circ}R$	500-850	500-850		o	x	x		o			Lube Oil Circuit	Note 3
ST16	Lube Oil	$^{\circ}R$	500-860	510-860			x	x				x		
SP16	Lube Oil	psig	0-100	40-60			x	x						
ST17	Lube Oil	$^{\circ}R$	500-850	510-760		o	x	x		o				
SP17	Lube Oil	psig	0-100	0-60		o	x	x		o		o x		
SN88	N.A.	rpm	0-6000	4500-5200		o				o			Dyno	
SX88	N.A.	ft-lb	0-30	5-15		o				o				

INSTRUMENTATION NOTES

1. For pressures 0 to 200 psig a Taber Model 217 or equivalent, pressure transducer will be used.
2. For higher pressures a Taber Model 206, or equivalent, will be used.
3. Std lab T/C.
4. LSK 31931-8, or equivalent.
5. For absolute pressures a Taber Series 254, or equivalent.

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(2) Digital data acquisition system (DDAS). DDAS obtains steady-state data for reduction by the offsite computer. The DDAS samples each of its parameters in turn, coverts them to binary-coded decimal, and stores then in sequence on an incremental magnetic tape. The sample rate for the 50-channel DDAS is one sample per channel per second; that is, any particular parameter will be measured once per second. Constants may be entered on the tape to identify the test type or run number. This information is supplemented by parameters on the test data sheet such as barometric pressure. The output from this system is a raw digital tape; no computations or further processing is done at the test site.

(3) Analog data acquisition system. Those parameters requiring continuous recording for the purpose of transient analysis are recorded on an analog frequency-multiplexing magnetic-tape recorder. The data thus recorded can be processed offline by an oscillograph recorder at the remote site for time-transient analysis. The basic data is still retained on the tape, so further data reduction is allowed as necessary (i.e., frequency analysis). In addition to the data parameters, a voice track is recorded to enable time correlation between the test and the recorded data.

Data reduction subsystems: These subsytems provide processing of both the analog and digital data. The analog data reduction has been mentioned, and a variety of other techniques exist within the facilities to process the data.

Digital data procesing is performed off-line at the Torrance facility. The three functions performed on the raw data are: (1) conversion to engineering units, (2) calculations, and (3) output of the engineering data in the required format. The basic program consists of the following operations:

(1) Read routine--reads the raw data from the data acquistion tape.

(2) Conversion routine--converts the raw data to engineering data.

(3) Calculation routine--computes the engineering data into the desired indirect data.

(4) Output routine--Arranges both the engineering and the indirect data into the proper format for engineering analysis. The tabulated format is that used in the design analysis computer program.

Test procedures.--The system was prepared for testing in accordance with the pretest checklist in fig. 34. This list defines the facility and APU-T conditions to be set during the test. The fully automatic startup was initiated by actuating the controller start switch. This was generally done under a 40-hp nominal load. Then the unit was allowed to run for 2 to 3 min. For the majority of power levels tested, this time was adequate for data sampling and stabilization. At the low power levels near 50 hp, about 4 to 5 min were required. Power settings were selected by actuating switches on the control console that opened and closed the required solenoid valves in the load bank. Power setting changes

PRELIMINARY — CHECK

INSTRUMENTATION

1. All equipment turned on and warmed
2. All R cals on
3. All visuals check out
4. Sufficient papers and tapes loaded

TEST CELL

1. Open GN_2, GO_2 and GH_2 manual source valves
2. 150 psi muscle pressure set
3. Determine sufficient test fluids available
4. Door open
5. Hot gas discharge duct in place
6. Spark plug wire connected to combustor
7. Ignitor box on
8. Put up appropriate chains and signs
9. Record source pressures
10. Close GN_2 purge (H_2 line) manual valve
11. Inspect and clear the test cell

CONTROL

1. 115 volt 60 cycle on
2. Three 28 vps on
3. 12V power supply to spark exciter on
4. Source solenoid valves closed
5. All solenoid valves closed

FINAL

(CHECK LIST FOR EACH TEST) — RUN NOS.

CONTROL CONSOLE

1. System controller off
2. Switch control panel to test position
3. Verify the following valves are closed: 97, 93, 95, 138 (unlock line valves for immediately repetitive tests)
4. Reset test run timer
5.[a] Open H_2 source valve 6
6.[a] Raise H_2 dome pressure to purge level.
7.

CONTROL CONSOLE (Continued) — RUN NOS.

8.[a] Open H_2 line valve 138 and purge entire H system with H
9.[a] Close H_2 line valve 138
10.[a] Open O_2 source valve 5
11.[a] Raise O_2 dome pressure to purge level (approx. 100 psi)
12. Open O_2 line valve 93
13.[a] Open O_2 dump valve 95 and purge entire system with oxygen
14.[a] Close O_2 dump valve 95
15. Set H_2 dome pressure, RP 67 to 560 psig
16. Set O_2 dome pressure, RP 66 to be 885 psig
17. Close O_2 line valve 93
18. Set speed and temperature limit conditions
19. Set pre-set dials on system controller
20. Verify the following panel lights are green: 5, 6, 92, 93, 95, 137, 138 and shut-down bypass
21. Verify red limit lights off
22. Verify green ready light on
23. Verify all hands ready to test
24. Verify all changes made since last run are accounted for

HOLD LEVEL (IF REQUIRED)

25. Verify instrumentation all on and running (except oscillograph)
26. System controller main power on
27. Verify +28 and -28V lights on
28. Verify failure lights off
29. Start countdown (oscillograph on at minus 2 seconds)

[a] Omit these steps for immediately repetitive tests.

Figure 34.--Pretest Checklist.

were almost instantaneous due to the fast action of the solenoid valves. Shutdown was completely automatic when the start switch was closed. The controller closed the O_2 shutoff valve and monitored the H_2 control valve to apply a 15-sec GH_2 purge at a 50-psig turbine inlet pressure. The purge time was reduced to 1 or 2 sec when cryogenic propellants were used to prevent thermal-shocking the unit. The pretest checklist was used as a guide for the post-test procedures.

When hot hydraulic oil was required, the oil was preheated before testing to minimize the time required for heating the oil with the pumps during the run. The pump inlet temperature was manually controlled by varying the facility oil cooler water flow.

The steam ejector was manually controlled. Generally, the ejector was operated only while the APU was running. This prevented condensed steam in the exhaust system from entering the pressure taps.

At the start of the test program, special checkout procedures were used before attempting the first run. The unit was driven at a reduced speed using ambient temperature GN_2 to verify proper functioning of the instrumentation. Emphasis was placed on the turbine speed pickups and other control instrumentation. For the first hot start, the speed was limited to 20 000 rpm by an adjustment on the controller provided for this purpose. Turbine inlet temperature and speed were gradually increased from test to test until design conditions (TIT = 1960 R, rpm - 63 000) were reached. There was a delay in the TIT rate to eliminate temperature spikes during lightoff.

Summary of conducted tests: The APU-T system tests, conducted from 9 September 1974 through 7 February 1975, accumulated 597 min total run time and 145 hot starts during the 5 months of testing.

The test conditions included the following: (1) operation with hot and ambient hydraulic fluid, (2) local and simulated altitude operation using the system ejector system, (3) operation with H_2 cooled to LN_2 and LH_2 temperatures, and (4) operation at progressively higher power levels approaching the design maximum of 400 hp. A chronology of the testing is summarized in table 9, which lists test conditions, the date of the test, and pertinent remarks.

The tests covered power ranges from 40 to 380 hp at both sea level and space simulation. The range of hydrogen temperatures to the test unit was from ambient to cryogenic (LH_2 temperature). Tests were conducted with both ambient and hot oil.

Test results.

Transient data: Performance during transient operation was predicted in ref. 1 as an aid to develop the control system. The turbine speed was to be controlled to 63 000 rpm and turbine inlet temperature (TIT) was to be controlled to 1960 R. Excellent control of these parameters was obtained as shown in figs. 35 through 41, which are oscillograph traces during various load changes. The main modification to the control concept was a delay in the TIT rate to eliminate temperature spikes during lightoff.

TABLE 9

SUMMARY OF APU TESTS

Date	Run No.	Events	Accum run time, min	Power, hp	Ambient pressure, psia	H_2 temperature	O_2 temperature	Hydraulic temperature	Remarks
9-9-74 to 9-10-74	1 to 6	1 to 6	-	-	-	-	-	-	Checkout runs
9-11-74 to 9-17-74	7 to 19	7 to 28	-	-	-	-	-	-	Turbine rollovers with GN_2 at room temperature
9-17-74 to 9-20-74	20 to 42	29 to 45	77	40 to 300	13.4	Ambient	Ambient	Ambient	Initial hot tests; TIT and turbine speed gradually increased from test to test
9-23-74 to 9-24-74	43 to 55	46 to 68	116	40 to 300	13.4	Ambient	Ambient	Ambient	Design conditions of TIT = 1960 R and rpm = 63,000 reached; first automatic starts
9-25-74 to 10-3-74	56 to 89	69 to 129	183	40 to 300	13.4	Ambient and LN_2	Ambient	Ambient	Checkout runs; experimentation with control valves; spark plug fouling problems
10-4-74	90	130 to 145	196	40 to 300	13.4	LN_2	Ambient	Ambient	Steady state and transient performance; fire from sparkplug at end of run
10-15-74	91 to 93	146 to 169	226	40 to 300	13.4	Ambient	Ambient	Ambient	Fire from spark plug terminated tests
10-25-74	94 to 95	-	234	-	-				Checkout Runs
10-28-74 to 11-7-74	96 to 105	170 to 219	247	40 to 300	13.4	Ambient	Ambient	Ambient	Modifications to spark plug gas supply system; attempts at performance
11-8-74	106 to 115	220 to 222	271	-	-	-	-	-	Checkout runs
11-11-74	116, 117	223 to 243	279	100 to 300	13.4	Ambient	Ambient	Ambient	Performance run at sea level
11-12-74	118	244 to 261	287	100 to 300	0	Ambient	Ambient	Ambient	Performance run - altitude simulation
11-18-74	119	-	-	-	-	-	-	-	Lost DAS
11-25-74	120	262 to 284	295	40 to 300	13.4	LN_2	LN_2	Hot	Performance tests with hot hydraulic fluid
11-26-74	121, 122	285 to 306	306	40 to 300	13.4	LN_2	LN_2	Hot	Performance tests with hot hydraulic fluid
11-27-74 to 12-4-74	123 to 129	309	307	-	-	-	-	-	Checkout runs
12-4-74 to 12-12-74	130 to 143	310 to 369	355	40 to 300	13.4 and 0	LN_2	Ambient	Hot	Performance tests; some data lost; reestablishing and stabilizing load bank characteristics
12-16-74	144	370 to 379	369	100 to 300	0	LN_2	Ambient	Hot	
12-17-74	145	396 to 414	381	40 to 200	0	LN_2	Ambient	Hot	Check hydraulic load bank for leaks
12-18-74	146	-	385	40 to 300	13.4	LN_2	Ambient	Ambient	
12-18-74	147	415 to 439	400	40 to 300	0	LN_2	Ambient	Hot	Performance run
12-18-74	148	440 to 445	404	200, 300	13.4	LN_2	Ambient	Hot	Performance run
12-19-74	149, 150	446 to 459	412	100 to 300	0	LN_2	Ambient	Ambient	Performance runs
12-19-74	151	460 to 478	430	40 to 380	0	LN_2	Ambient	Ambient	Performance run
1-8-75	152, 153	479 to 481	431	-	-	-	-	-	Checkout runs
1-8-75	154	482 to 493	447	40 to 200	0	LH_2	Ambient	Ambient	First test at LH_2 temperature
1-9-75	155 to 159	511 to 518	459	-	0	LH_2	Ambient	Ambient	Unsuccessful attempts to run at higher power
1-10-75	160	519 to 533	467	40 to 200	0	LH_2	Ambient	Ambient	Shutdown at 300 hp
1-13-75 to 1-15-75	161 to 169	535 to 560	488	-	0	LH_2	Ambient	Ambient	Minor system problems prevented 300 hp operation
1-15-75	170	561 to 597	507	40 to 300	0 and 13.4	LH_2	Ambient	Ambient	Successful operation at high power levels
1-15-75 to 1-20-75	171 to 179	598 to 609	522	-	-	-	-	-	Shutdowns occurring immediately after start
1-21-75	180	610 to 634	528	40 to 300	13.4	LH_2	Ambient	Hot	Verify 300 hp operation; oil leak end of run
1-23-75 to 1-24-75	181 to 184	635 to 669	540	40 to 200	13.4	LH_2	Ambient	Ambient	Chamber pressure running high for a given hydraulic flow; hydraulic pumps damaged
2-5-75 to 2-6-75	185 to 187	670 to 705	585	40 to 200	13.4	LH_2	Ambient	Ambient	Shakedown with rebuilt pumps; performance data obtained; spark plug tip burned off
2-7-75	189 to 192	706 to 708	597	-	-	-	-	-	Checkout runs to determine cause of spark plug burnouts; testing terminated

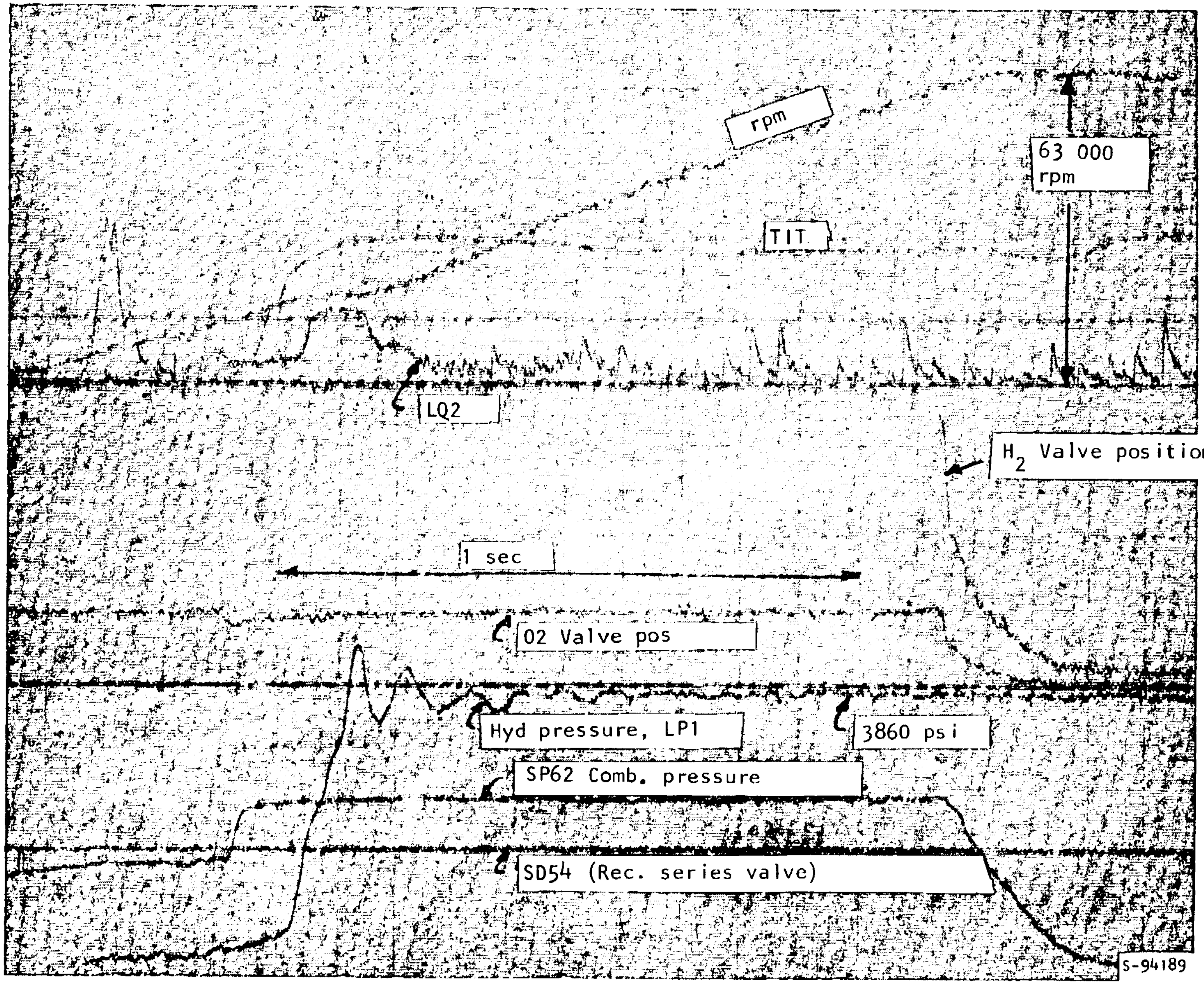

Figure 35.--Run 53 Start Transient.

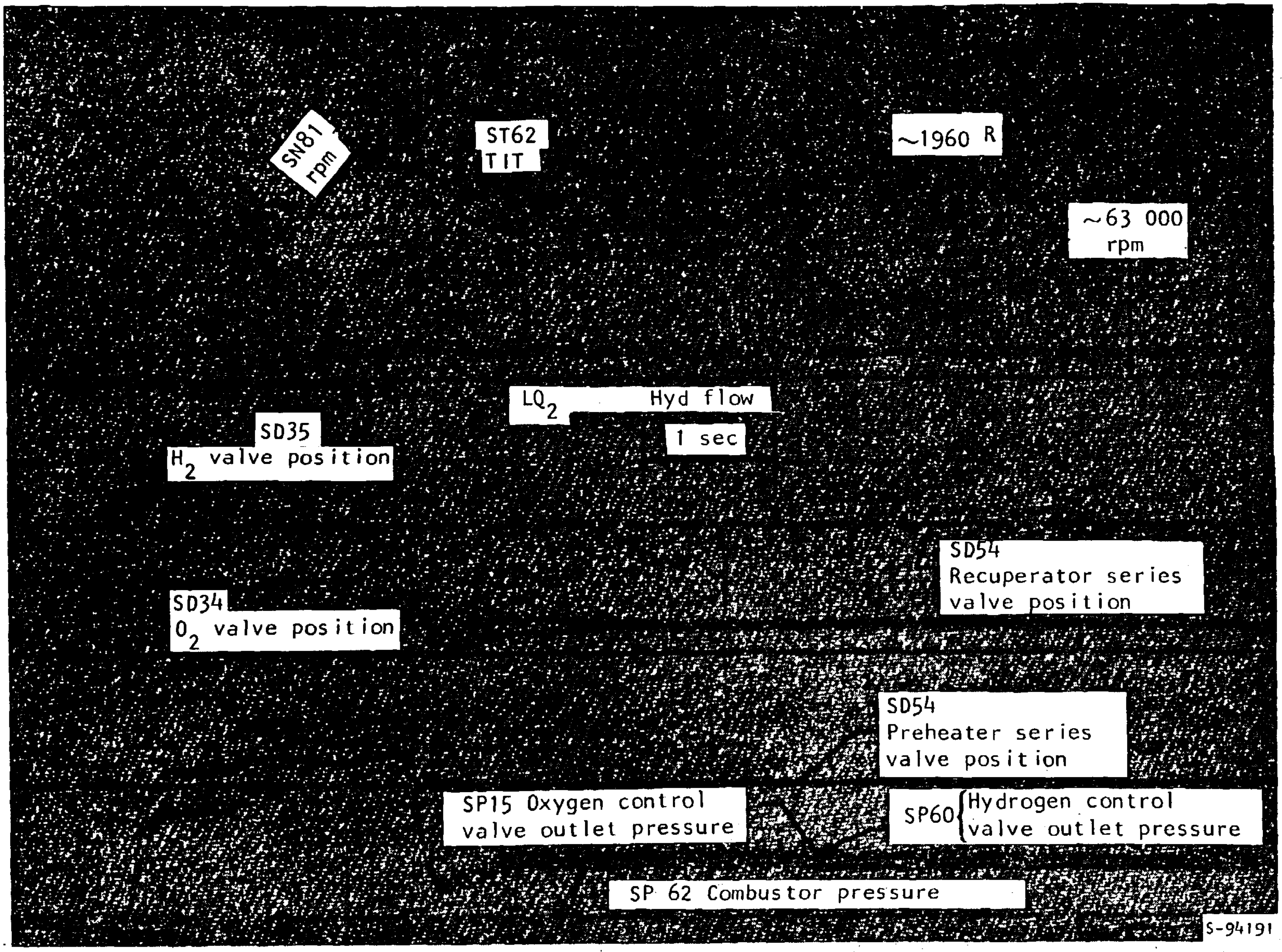

Figure 36.--Run 117, Startup to 40 shp.

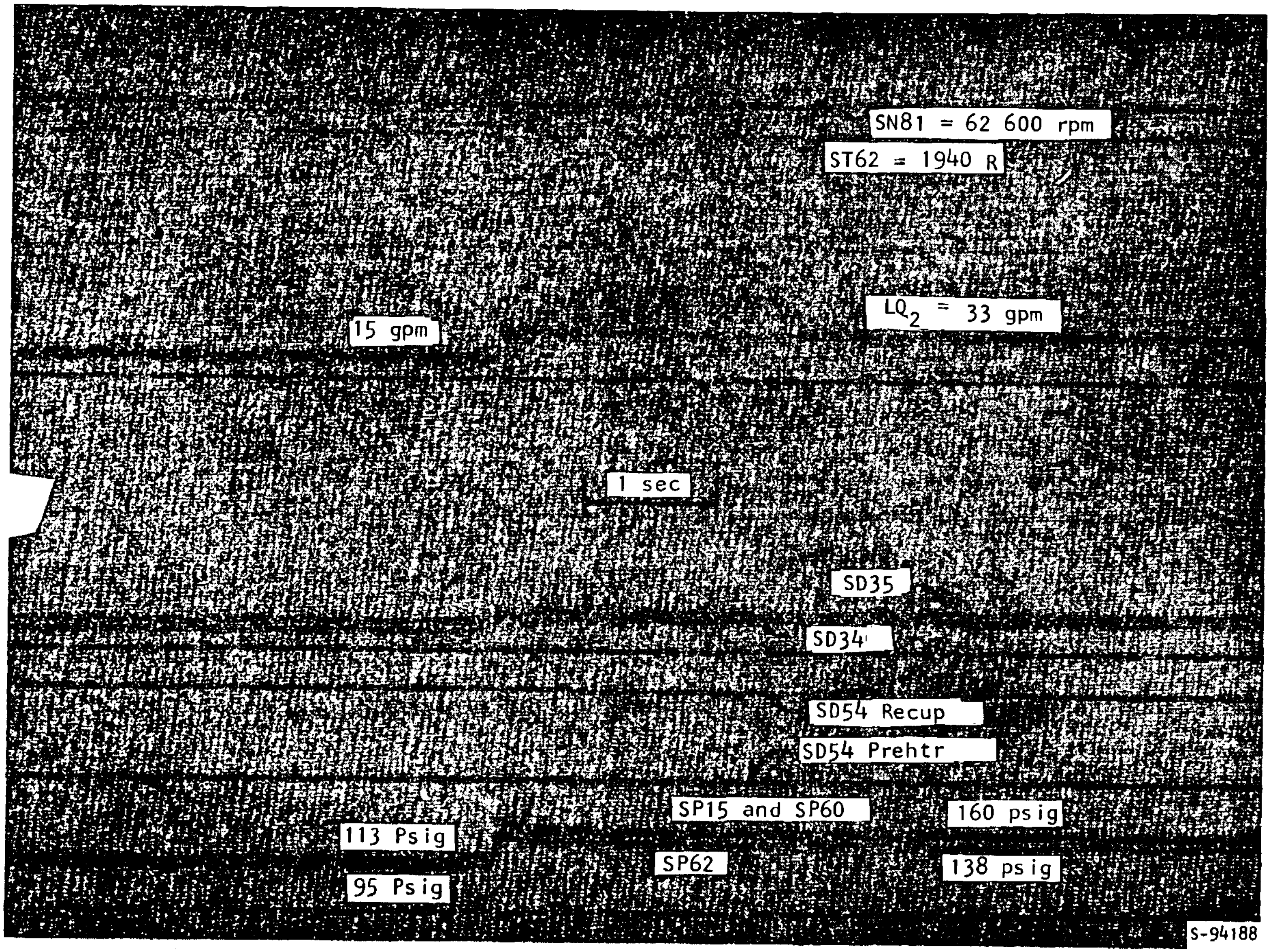

Figure 37.--Run 117, 40 to 100 shp.

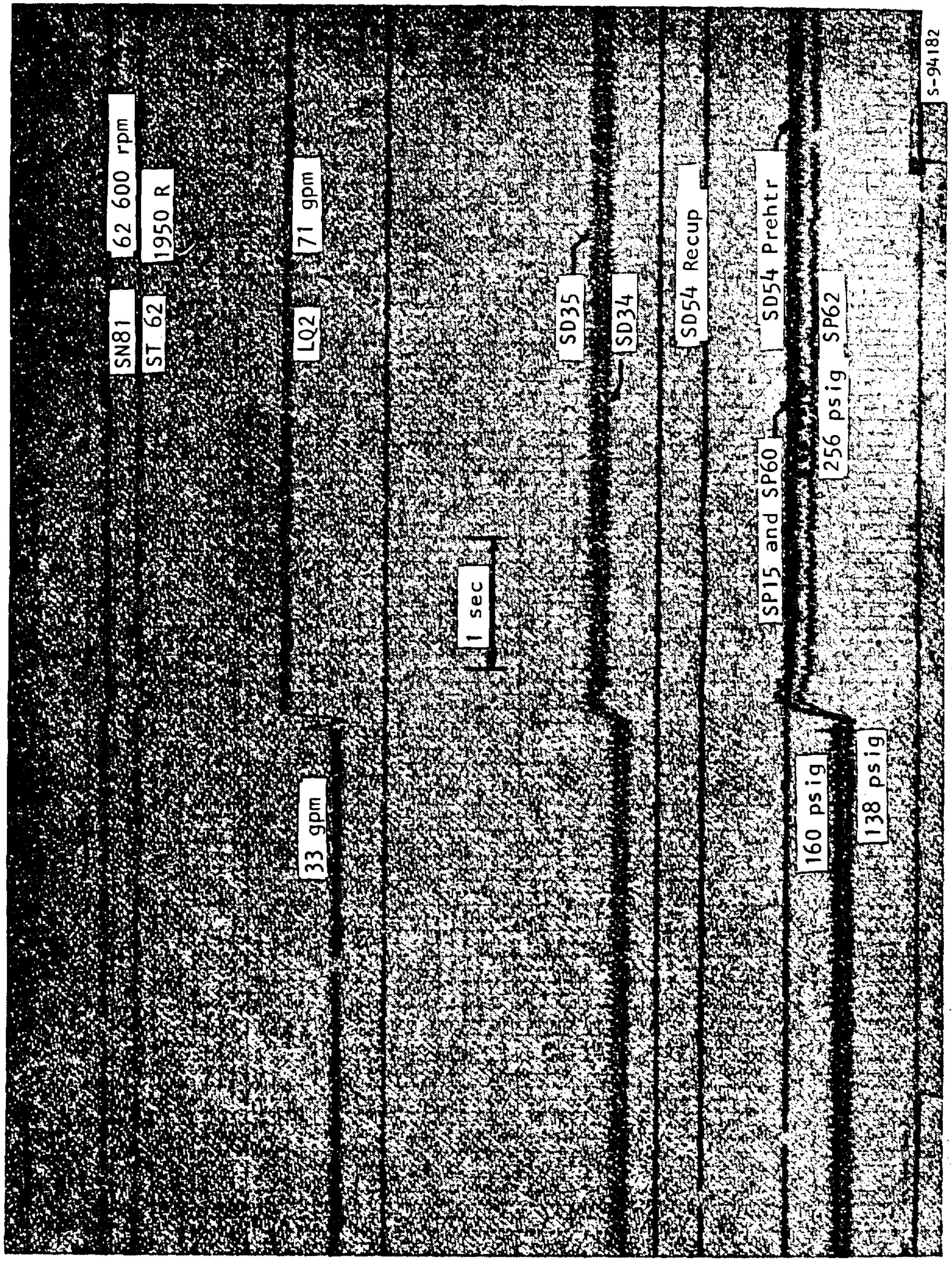

Figure 38.--Run 117, 100 to 200 shp.

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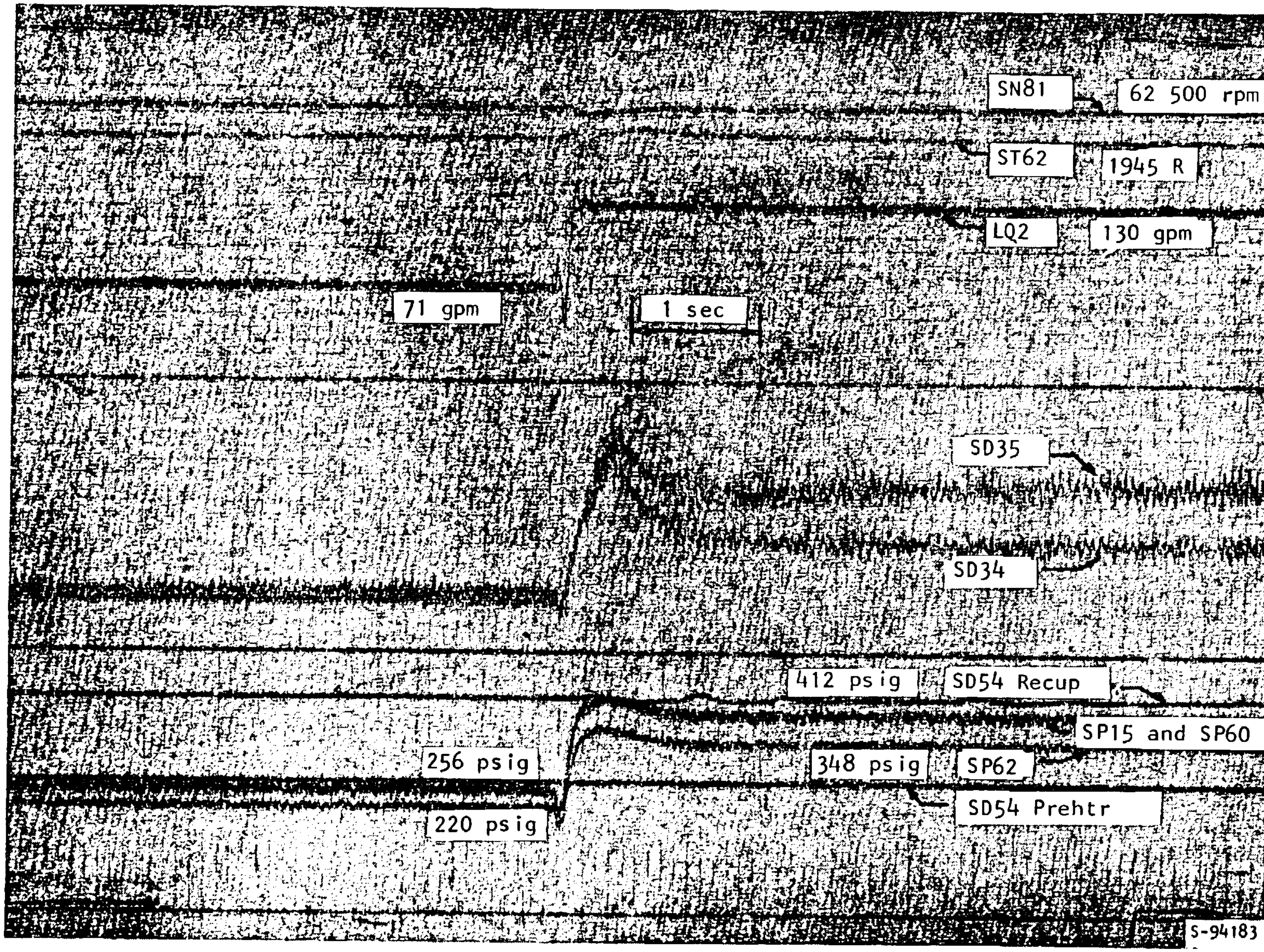

Figure 39.--Run 117, 200 to 300 shp.

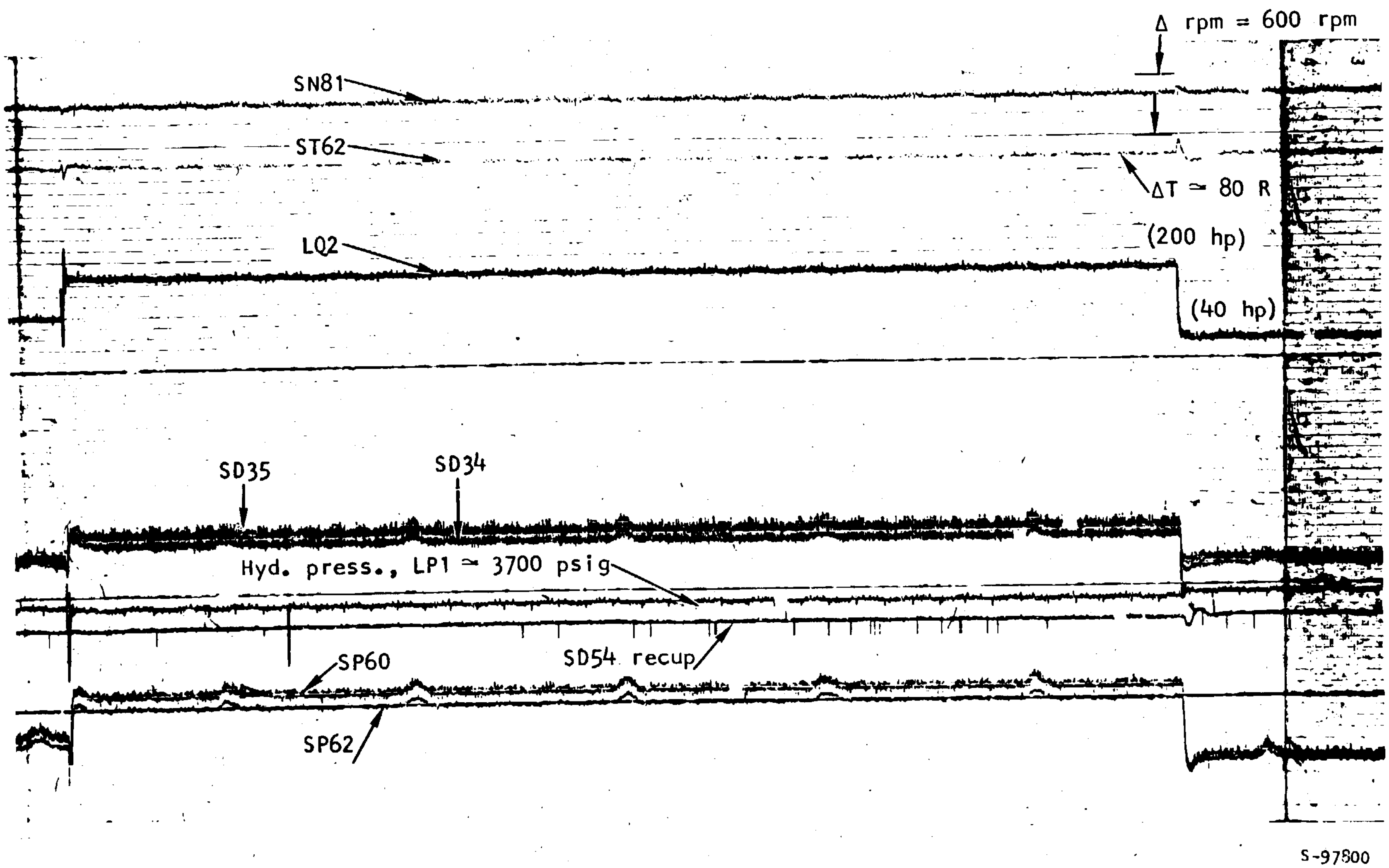

Figure 40.--Run 78-80, 200 to 40 shp.

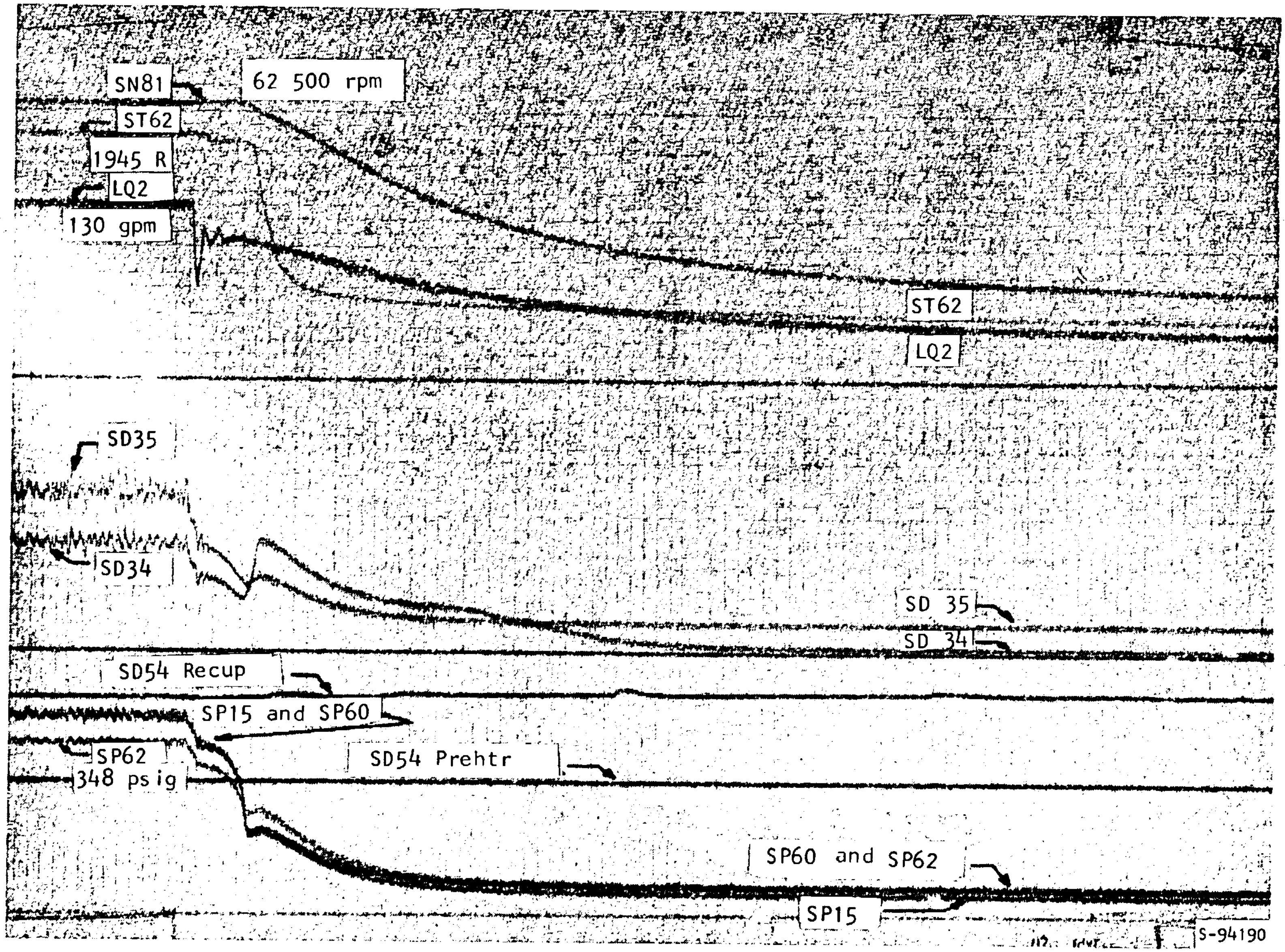

Figure 41.--Run 117, 300 shp to Shutdown.

The transient performance for the APU-T tests was recorded on an oscillograph to determine the response and control characteristics during startup, shutdown, and load changes. The data in figs. 35 through 41 was representative of the many tests conducted.

Figure 35 shows an automatic start with zero applied load. The turbine design speed of 63 000 rpm was reached approximately 1.25 sec after lightoff. Full hydraulic pressure was available 0.25 sec from lightoff. Steady-state turbine inlet temperature was reached 5 sec after lightoff.

Similar results were obtained during a startup to a power setting of 40 shp (fig. 36). Turbine design speed was attained about 2.5 sec after lightoff. Steady-state turbine inlet temperature occurred 3 sec later; it was purposely delayed to avoid temperature spikes during lightoff as previously mentioned.

A sequence from 40 to 300 shp in load steps of approximately 100 hp is shown in figs. 37 through 39. During this entire sequence, including the load steps, turbine speed was controlled within 1 percent of the mean speed of 63 000 rpm. Except for the immediate changeover in horsepower levels there was a standard deviation of 64 rpm or about 0.1 percent of the mean, and TIT was controlled to a mean of 1947 R with a standard deviation of 3 R. At the exact time when horsepower changed, TIT varied by about ± 40 R.

This excellent control of turbine speed and TIT was clearly demonstrated at the higher horsepower levels, as shown in fig. 39. At high power levels, the propellant valves were unchoked and thus, to obtain the same percent changes in propellant flow as at low power levels, they had to move farther. Thus, at 300 shp, the fluctuations were larger than at 200. These larger valve movements were indicated by the values SD35 and SD34, indicating hydrogen and oxygen valve position, respectively.

Figure 40 shows approximately a 160-hp stepdown from 200 to 40 hp. As with the power step increases, power level was changed without exceeding allowable turbine inlet temperatures or turbine speed.

During shutdown, fig. 41, there was smooth decay in both turbine speed and TIT. No spikes or overspeed conditions occurred.

The combustor chamber pressures (SP62) were fairly steady at any particular power setting, as shown by the transient data oscillograph output. At high power levels, near 300 shp for example, the variation in chamber pressure was about ± 1-1/2 percent from the operating pressure, or about ± 4 psia.

The performance of the propellant conditioning system shown in fig. 42 is for a typical test run (run 170) conducted with gaseous hydrogen cooled down to LH_2 temperature. The data is shown from startup through power levels of 58, 96, 202, and 295 hp. Inlet hydrogen to the system was rapidly cooled down and reached fairly steady values in about 1 min. The control of hydrogen temperatures out of the equalizer and the regenerator was excellent. The hydrogen inlet temperature to the combustor was to be controlled to 750 R, and at the higher power levels it was controlled within 15 R. Both hydrogen

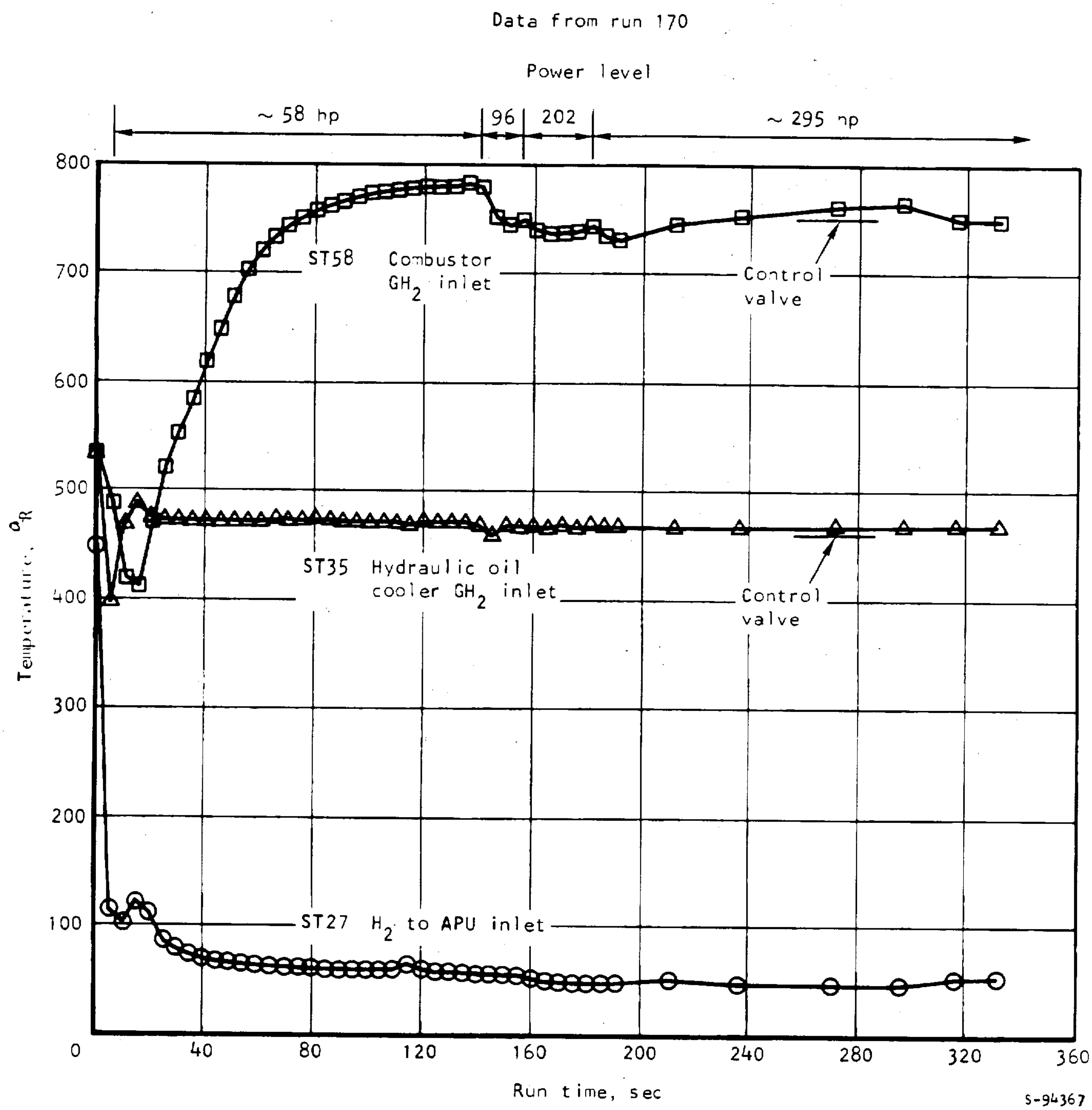

Figure 42.--Propellant Conditioning System Performance

streams out of the regenerator were to be approximately equal with the hydrogen inlet temperature to the hydraulic oil cooler, which was controlled to 460 R. Over the entire power range, the hydrogen inlet temperature (ST35) was about 10° higher. Thus, the propellant conditioning system objectives were accomplished, with excellent control of hydrogen temperature.

Steady-state data.--Data from the entire test series were examined and the test events listed in table 10 were selected as the most stable points for steady-state analysis. The data correlations obtained from these events are presented later in this section.

A computer program was written to aid in data reduction and analysis. This program presented test data in both engineering units and a format identical to that used in SSAPU performance predictions (ref. 2). An example of the computer output for run 180, event 631, conducted at 305 hp, is shown in table 11. For the first part, the data in engineering units has pressures in psig, temperature in degrees Rankine, and flow in gpm. The symbols are defined in table 8. The definitions for the calculated values are included in Appendix B. The other parts of the format give overall and component performance in a form that can be compared easily with predictions. The key station pressures and temperatures also are tabulated. In these parts, pressure is in psia.

Combustor: In the APU-T system tests, combustor inlet temperatures were controlled to 750 R and turbine inlet temperature was controlled to a nominal setting of 1960 R. Thus the combustor propellant flows essentially were fixed at a nominal oxidizer to fuel ratio of 0.65. During actual operation, the O/F ratio varied from 0.60 to 0.67 because of changes in test conditions.

Ignition of the hydrogen-oxygen propellants was obtained using a spark plug in which oxygen gas was fed into the annulus between the electrode insulator and the spark plug body. During combustor operation after light-off, the spark plug was cooled with gaseous hydrogen.

For steady-state operation, the combustor characteristic velocity C* was determined for the range of combustor chamber pressures experienced during the system tests. This data, with the C* efficiency calculations, is presented in fig. 43. The characteristic velocity varied from 8000 to 9000 ft/sec and C* efficiencies were nominally 108 percent. Chamber pressure did not have an appreciable effect on combustor performance. This result was consistent with test results of the prototype combustor.

A significant problem experienced in the test program was spark plug burnout. Design modifications and changes to the test procedure resulted in no plug failure occurrences for the majority of APU-T system tests. Near the end of the test program, however, the spark plug tips began to melt, but insufficient time remained in the test program for a detailed investigation or corrective action. A discussion of the spark plug burnout problem can be found in the section titled, Analysis of Test Results, and it includes possible solutions that could not be checked out experimentally.

TABLE 10

TEST EVENTS SELECTED FOR STEADY-STATE ANALYSIS

Run No.	Event	Hydraulic flow, gpm	Pump shaft power, hp	H_2 temp, R	Hydraulic oil temp, R	$P_{ambient}$, psia
90	131	7.97	47	286	579	13.4
	133	48.94	140	272	580	13.4
	138	66.99	183	224	584	13.4
	143	126.65	320	198	592	13.4
117	230	34.82	107	542	580	13.4
	235	71.02	193	539	588	13.4
	241	129.52	327	537	605	13.4
118	251	29.17	94	545	585	0
	255	67.17	183	542	588	0
	260	129.67	328	539	605	0
120	270	10.43	52	498	687	13.4
	276	41.62	123	375	705	13.4
122	308	129.37	327	213	703	13.4
131	315	8.72	49	463	679	0
136	366	6.39	44	417	688	0
144	374	10.43	52	414	694	0
	378	29.72	95	318	715	0
	386	71.67	194	224	738	0
	394	130.37	330	196	744	0
145	400	22.47	78	421	695	0
	406	29.42	94	315	722	0
	412	70.52	191	218	-	0
147	420	13.62	59	353	689	0
	424	88.92	228	223	732	0
	432	31.62	99	227	773	0
148	442	29.52	94	287	665	13.4
149	449	13.08	58	385	588	0
151	464	76.22	205	207	722	0
	467	139.07	351	177	740	0
	469	28.32	92	205	750	0
	474	13.92	59	223	770	0

TABLE 10.--Continued

TEST EVENTS SELECTED FOR STEADY-STATE ANALYSIS

Run No.	Event	Hydraulic flow, gpm	Pump shaft power, hp	H_2 temp, R	Hydraulic oil temp, R	$P_{ambient}$ psia
154	501	13.08	58	51	-	0
	510	29.47	94	49	-	0
160	525	13.07	58	60	-	0
	529	30.22	96	53	-	0
	534	74.92	202	50	-	0
161	541	13.12	58	63	-	0
163	548	13.03	58	56	-	0
170	573	117.92	299	52	-	0
	579	117.72	299	52	-	13.4
	585	74.82	202	46	-	13.4
	593	29.72	95	50	-	13.4
	597	13.33	58	48	-	13.4
180	631	120.17	305	53	743	13.4
187	688	31.72	98	56	574	13.4
	692	11.39	52	58	590	13.4
	695	31.47	98	50	578	13.4
	698	11.38	52	53	593	13.4
	705	74.22	197	46	584	13.4

TABLE 11

RUN 180, EVENT 631

*** H2O2 APU PERFORMANCE ***

DATE 1-22-75
TIME 15- 1-30

READING 631
BAROMETER 13.41 PSIA

DATA IN ENGINEERING UNITS

RP66	869.70	RP67	554.93	DL68	13.75	DL69	13.76	SP5	840.17	SP7	487.63	DH68	77.02	DH69	57.45
SP18	126.08	SP63	52.62	SP27	514.63	SP58	454.93	SP62	333.28		1.27	SP64	1.27	LP1	3603.05
LP2	66.80	RT66	511.99	RT67	523.52	ST5	517.92	ST7	688.56	ST16	549.69	ST17	526.20	ST18	743.18
ST19	667.71	ST27	53.16	ST31	364.04	ST35	469.06	ST39	615.15	ST41	496.24	ST45	507.34	ST47	1262.82
ST51	1083.71	ST56	365.95	ST57	733.58	ST58	749.57	ST62	1944.46	ST65	1426.88	ST66	909.31	ST84	615.15
ST86	586.08	LT2	714.37	LT5	526.26	LT6	557.14	SN816	2598.38	SQ19	13.37	SQ83	0.52	SQ85	0.91
LQ2	120.17	LQ5	13.27												

CALCULATIONS

101	7.537	102	4.891	103	0.649		0.000	104A	304.723	105	2.447	106	********	107	3.324
160	1.368	108	23.589	109	********	110	12.429	111	715.008	112	12.095	113	370.285	114	336.628
115	313.436	116	176.518	117	47.049	118	43.836	119	24.687	120	247.939		0.000	1218	8.712
	0.000	1210	31.905	121E	145.630	121F	168.823	122	167.805	123	89.495	124	5.750	125	1.786
126	3.676	127	3.860	128	0.301	129	0.696	130	0.418	131	0.473	132	0.532	133	0.275
134	0.207	135	0.439	136	0.821	137	0.562	138	-0.074	139	0.791	140	7970.828	141	9100.251
142	2653.188	143	3016.490	144	3713.218	145	4361.277	146	281.575	147	124.849	148	********	149	********
150	421.813	151	-200.344	152	********	153	3418.525	154	********	155	1917.960	156	8168.820	157	7898.083
158	103.427	159	4.699	161	0.147										

106	31493.	109	1898380.
145	4361.277	148	15102.356
149	13899.759	152	27589.673
153	3418.525	154	24171.149

NOTE: "Data in Engineering Units" - See table 8 for definition calculations;
See Appendix B for definitions.

TABLE 11.--Continued

AMBIENT PRESSURE 13.41 H2-O2 APU 1-22-75 15- 1-30

STATION	PRESSURE	TEMPERATURE	RHO	ENTHALPHY	STATION	PRESSURE	TEMPERATURE	RHO	ENTHALPHY
01					41		496.247		********
02					42				
03					43				
04					44				
05	853.595	517.921		0.000	45		507.342		0.000
06				0.000	46				
07	501.057	688.568			47		1262.820		********
08					48				
09					49				
10					50				
11					51		1083.718		********
12	90.440	549.691			52				
13	70.874	526.205			53				
14					54				
15					55				
16					56		365.951		0.000
17					57		733.581		0.000
18	139.500	743.189			58		749.570		********
19		667.716			59				
20					60				
21					61				
22					62	346.701	1944.464		
23					63	66.046			
24					64	14.697			
25					65		1426.886		
26					66	0.000	909.314		
27	528.052	53.169		********	67				
28					68				
29					69				
30					70				
31		364.049		0.000	71				
32					72				
33					73				
34					74				
35		469.060		0.000	75				
36					76				
37					77				
38					78				
39		615.157			79				
40					80	13.418			

TABLE 11.--Continued

* CONDITION * NO BYP AMBIENT PRESSURE 13.41 PSIA 1-22-75 15- 1-30

HYDRAULIC POWER	247.93	GEARBOX LOSS	4.69	FIRST STAGE POWER	0.00	SPC	2.447	AMW	3.32
HYDRAULIC PUMP	0.00	LUBE PUMP	0.00	SECOND STAGE	0.00	O/F	0.649		
TOTAL GEARBOX	304.72			TOTAL TURBINE	0.00	PT OUT	0.000		

TURBINE INFORMATION

FLOW	12.429	PRESSURE	346.70	14.69	EFFICIENCY 1ST	0.000	A1	0.147	A3	0.000
SPECIFIC HEAT RATIO	1.368	TEMPERATURE	1944.4	1426.8	EFFICIENCY 2ND	0.000	A2	0.000	A4	0.000
PRESSURE RATIO	23.589	ENTHALPHY	0.000	0.000	EFFICIENCY TOTAL	47.049	NDOT	0.	N	62598.

CONTROL VALVES

	PREHEATER BYPASS	RECUPERATOR BYPASS	O2 PRESS REG	OXYGEN FLOW	HYDROGEN FLOW
TEMPERATURE	1262.82	586.08	688.56	688.56	749.57
PRESSURE IN	0.00	0.00	0.00	501.05	749.57
PRESSURE OUT	0.00	0.00	501.05	0.00	0.00
EFFECTIVE AREA	0.00000	0.00000	0.00000	0.00000	0.00000
FLOW	3.860	1.786	4.891	4.891	7.537

HX NO.	FLOW	IN PRESS	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.
1 COLD SIDE	7.537	528.05	0.00	53.16	364.04	******	0.0	0.301	7970. BTU/MIN
HOT SIDE	3.676	0.00	0.00	1083.71	365.95	******	0.0	0.696	6 PASS COUNT

HX NO.	FLOW	IN PRESS	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.
3 COLD SIDE	7.537	0.00	0.00	364.04	469.06	******	0.0	0.418	2653. BTU/MIN
HOT SIDE	7.537	0.00	0.00	615.15	496.24	******	0.0	0.473	6 PASS PARALL

HX NO.	FLOW	IN PRESS	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.
5 COLD SIDE	7.537	0.00	0.00	469.06	615.15	******	0.5	0.532	3713. BTU/MIN
HOT SIDE	89.49	139.50	66.04	743.18	667.71			0.275	4 PASS COUNT

HX NO.	FLOW	IN PRESS	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.
6 COLD SIDE	7.537	0.00	0.00	496.24	507.34	******	******	0.207	281. BTU/MIN
HOT SIDE	12.095	90.44	70.87	549.69	526.20			0.439	4 PASS COUNT

HX NO.	FLOW	IN PRESS	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.
8 COLD SIDE	5.750	0.00	0.00	507.34	1262.82	0.0	******	0.821	15102. BTU/MIN
HOT SIDE	12.429	14.697	0.000	1426.88	909.31			0.562	2 PASS COUNT

HX NO.	FLOW	IN PRESS	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.
9 COLD SIDE	7.537	0.00	0.00	733.58	749.57	0.0	******	-0.074	421. BTU/MIN
HOT SIDE	4.891	853.59	0.000	517.92	688.56	0.0	******	0.791	1 PASS PARALL

EXHAUST DUCT	PT	PS	MACH
INLET	0.000	0.000	0.000
EXIT	13.418	0.000	0.000

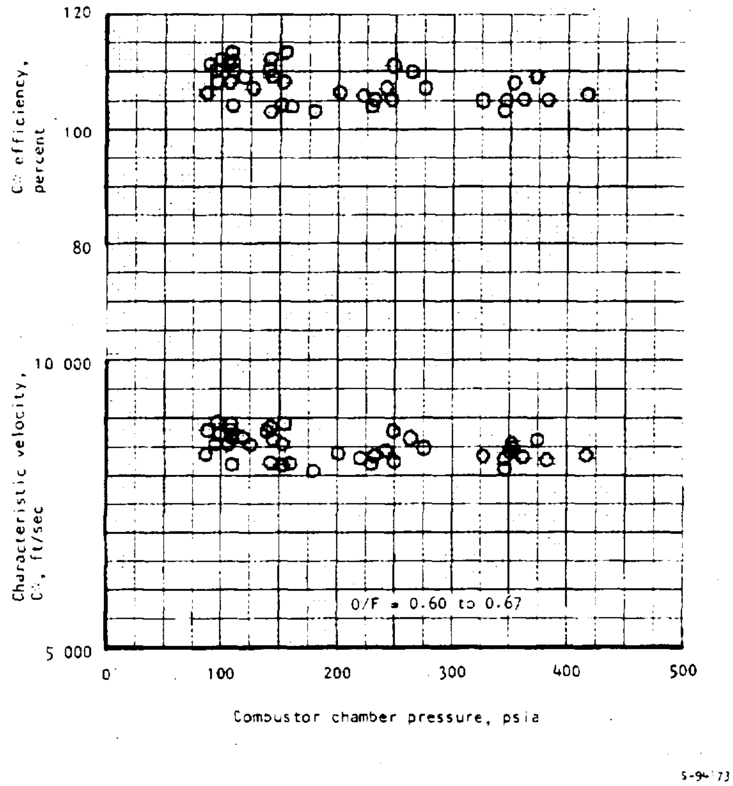

Figure 43.--Combustor Characteristic Velocity During System Tests.

Turbine: Overall turbine efficiency for the design characteristics of table 6 was predicted. In figs. 44 and 45, overall efficiency predictions were plotted as a function of: (1) overall pressure ratio for fixed turbine speed at several back pressures, and (2) shaft power for fixed turbine speed at several back pressures. Turbine performance as illustrated by these figures was used to predict overall reference system performance as presented in ref. 2. For example, at sea level, 400-hp power requirements, predicted turbine efficiency was 54 percent at an overall pressure ratio of 22. For space operation at the same power requirement, the predicted turbine efficiency was 51 percent at an overall pressure ratio of 37.

For the APU-T system tests the calculation procedures for the turbine efficiency are presented in Appendix B. Different methods were used to calculate turbine performance from: (1) the ΔT across the turbine, (2) the measured shaft horsepower and, (3) calculated shaft horsepower from heat rejection. Turbine efficiency calculated from these three methods, respectively, was in the engineering data reduction (Appendix C) calculations 117, 118, and 119. Gearbox losses were calculated from heat rejection to the lube oil.

All of these calculations were not exact because of measurement errors and the difficulty to assess component performance from system tests. In the heat rejection method (119), for example, calculated efficiency increased with

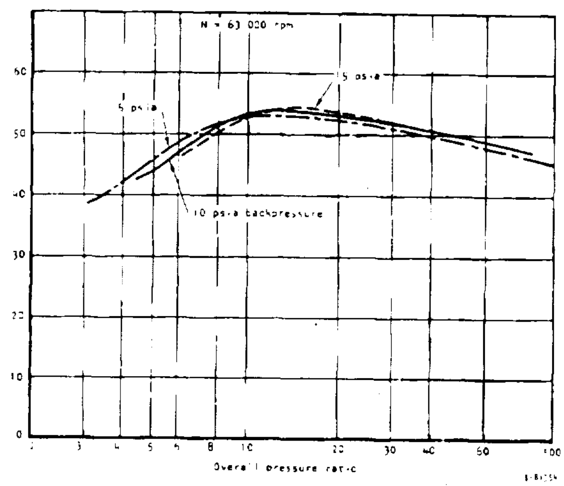

Figure 44.--Turbine Efficiency vs Pressure Ratio.

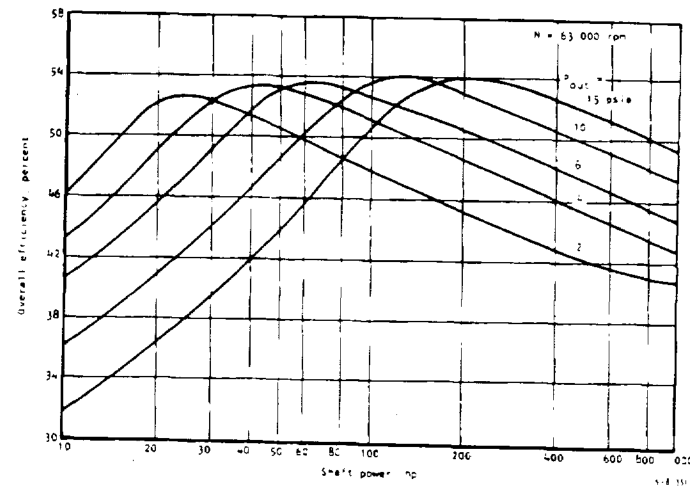

Figure 45.--Turbine Efficiency vs Developed Power.

run time at any particular power level. This was a result of measured temperature starting to stabilize. The ΔT method had large errors at low power levels because of nitrogen buffer gas leakage into the turbine exhaust torus. Temperature measurements in the torus were lowered and, therefore, the measured ΔT across the turbine was too high and resulted in a high calculated turbine efficiency. At high power levels, the propellant flow was significantly higher, reducing this cooling effect.

Taking the calculations at 300 gearbox shaft horsepower as representative of turbine performance from run 117, reading 241, and run 170, reading 579, an efficiency range of 47 to 48 percent was calculated by the ΔT method, a range of 44 to 45 percent was calculated from measured shaft horsepower, and a range of 38 to 40 percent was calculated from the heat rejection method. Because the calculation from heat rejection was dependent on stabilization time, it was the least accurate of the three methods.

Gearbox loss calculated by heat rejection to the lube oil was 5 to 6 hp, which is compatible with the 44 to 45 percent turbine efficiency calculated from measured shaftpower, but does not compare favorably with the 28 hp gearbox losses measured during gearbox dynamometer tests. On the other hand, gearbox losses back-calculated based upon ΔT-calculated turbine efficiency of 47 to 48 percent correlate more closely with the dynamometer tests; that is 18 to 25 hp compared to 28 hp. Accordingly, the range of 44 to 48 percent efficiency as calculated from measured shaft power and ΔT was used for the APU-T turbine efficiency. This range of efficiencies was plotted versus overall turbine pressure ratio for the available steady-state points at different turbine back pressures in fig. 46. The turbine efficiency was about 4 to 8 points lower than predicted over the range of pressure ratios tested. The lower performance was traced to first-stage turbine seal leakage.

C-2

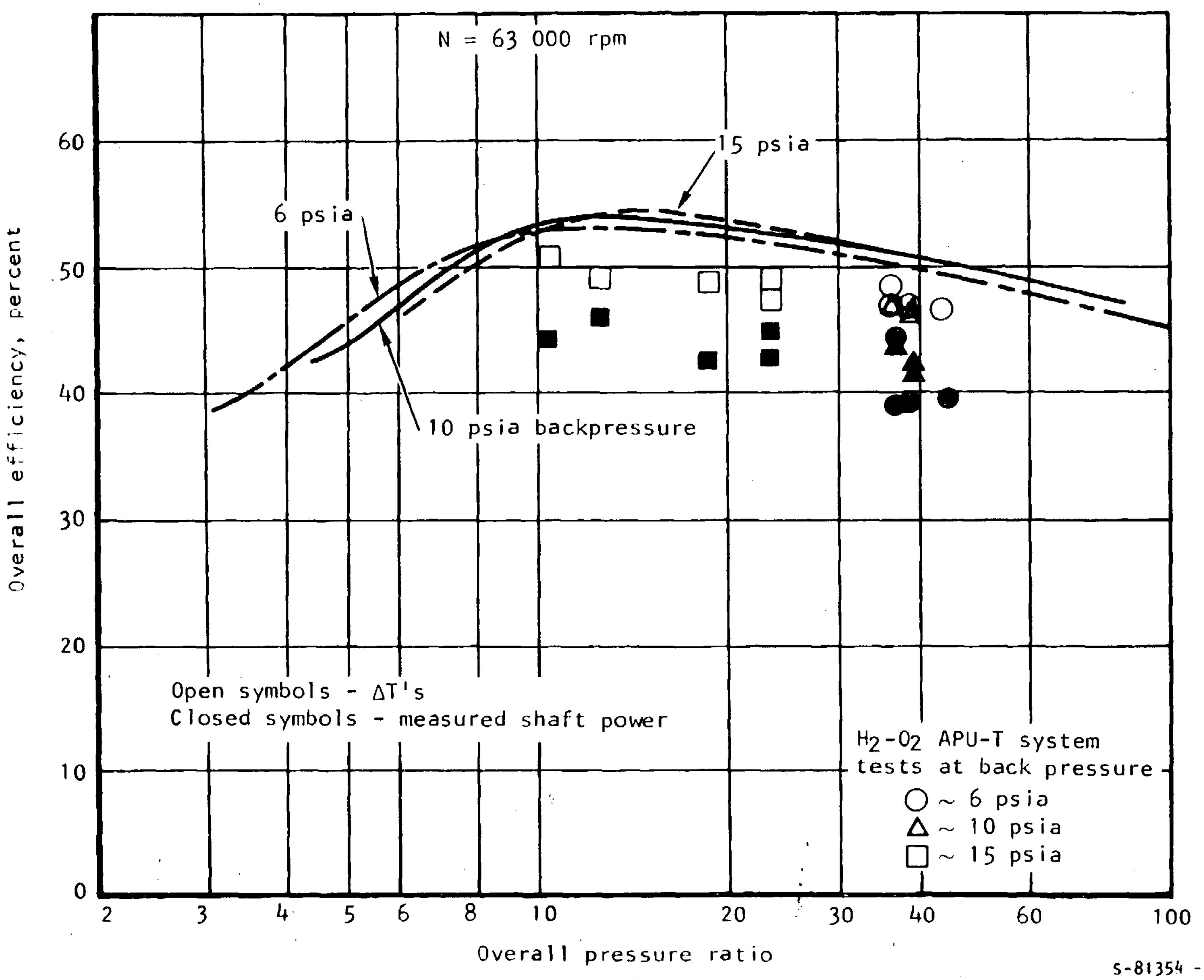

Figure 46.--Turbine Efficiency vs Pressure Ratio.

Heat exchangers: APU tests were run with ambient temperature oxygen (except for a few runs) and with hydrogen temperature varied from ambient temperature to 50 R. In terms of heat exchanger performance, the most interesting tests were those run at liquid hydrogen temperatures near 50 R, because in these cases the heat exchangers had to work the hardest. Tests made at LH_2 temperatures were from run 154 to run 192.

The time for the system temperature to stabilize was fairly long, as shown in fig. 47. At high power levels of 200 and 300 hp, heat exchanger temperatures stabilized in about 140 sec. This was determined from hydraulic oil temperatures at both the inlet and outlet of the hydraulic oil cooler for test runs where the power level was reached rapidly on APU ignition. Most tests that were conducted at low power levels immediately after APU ignition did not have sufficient run time for temperatures to stabilize. The exception was run 154, where the APU was run at approximately 55 hp for about 9 min. In this run, the inlet temperature measurement to the hydraulic oil cooler was incorrect, so only outlet temperatures were available. The data was not smooth; oscillations occurred about 3 min into the run. With the exception of the data at 425 sec into the run, it appears that at a low power level of 55 hp, temperatures stabilized in 4 to 5 min or about twice as long as the higher power levels. Therefore, care was exercised in selecting steady-state data to obtain heat exchanger performance to ensure that system temperatures had stabilized.

The steady-state data shown in figs. 48 through 55 were for tests conducted at both ambient back pressure and space simulation for power levels from 58 to 300 hp. Hydrogen temperatures were not directly measured for several heat exchanger locations as indicated by the star symbol in these figures. For purposes of heat transfer calculations, the temperature assumed at these locations was that measured immediately upstream or downstream in series with the flow. The temperature distributions were fairly similar at both ambient back pressure and space simulation for any particular power level. The heat transfer increased from space simulation to ambient back pressure because of increased propellant flow.

The equalizer performance was below predicted performance with oxygen temperatures into the combustor about 50 to 60 R lower than hydrogen. The temperature across the equalizer showed a rise both on the oxygen and hydrogen sides, which is an impossibility. To raise the oxygen temperature about 170 R for the tests would require only an 11 R decrease in hydrogen temperature because of the difference in Cp's of the gases. This is probably within the band of the hydrogen temperatures measured. Thus, only oxygen measurements were used for the equalizer heat transfer.

For a better understanding of the performance of the heat exchangers, the heat transfer as Btu/min was plotted in figs. 56 and 57 at the various horsepower settings of run 170, which was conducted at ambient back pressure and with ambient hydraulic oil. For ease of presentation, only cold side values were used in the plots. Run 170 was used because the entire power level was traversed in this test and possible variations from run to run in data thus were eliminated. The data was compared with computer predictions (ref. 2) for hot hydraulic oil, therefore the heat transfer, particularly in the hydraulic oil

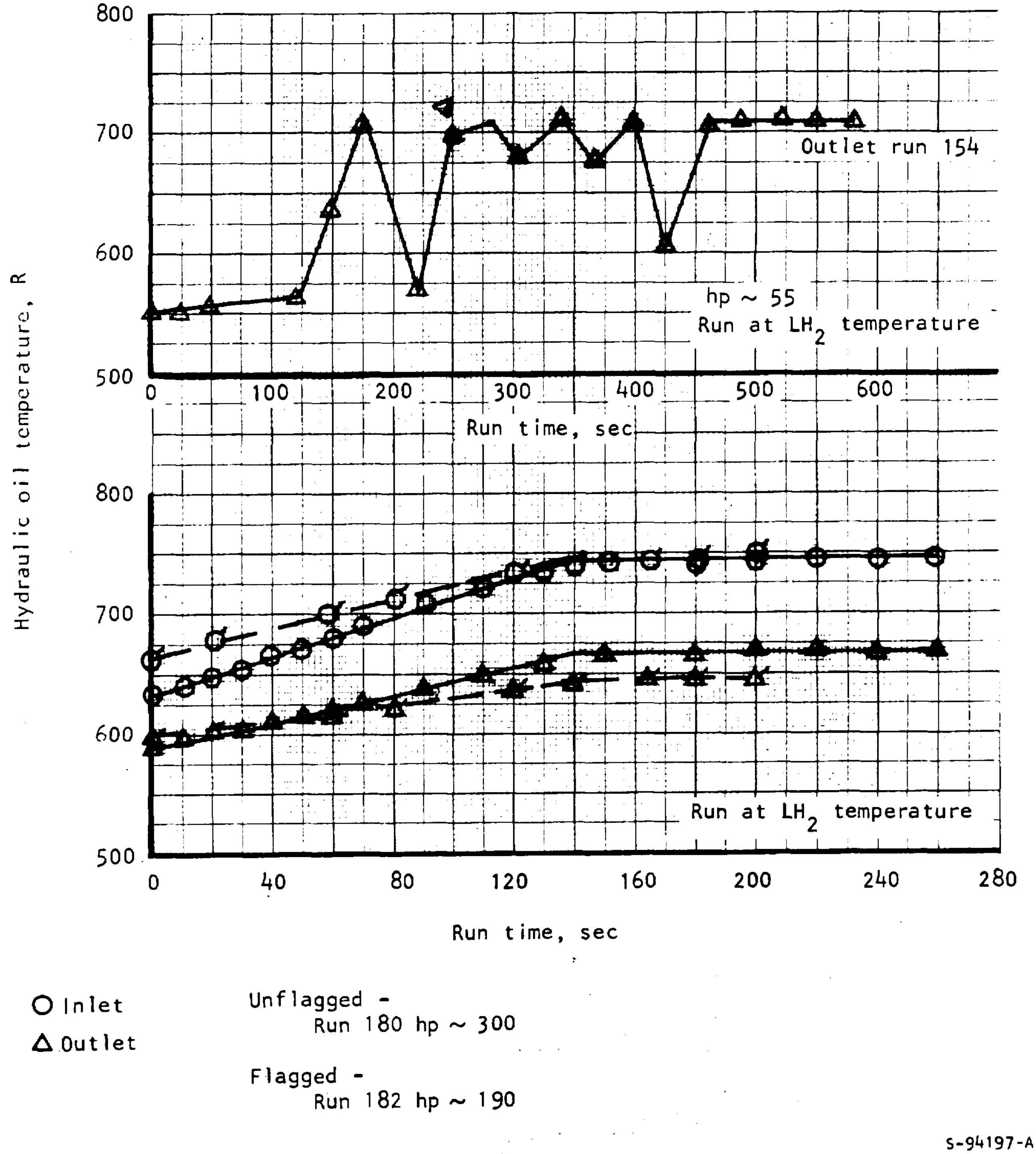

Figure 47.--Required Stabilization Time.

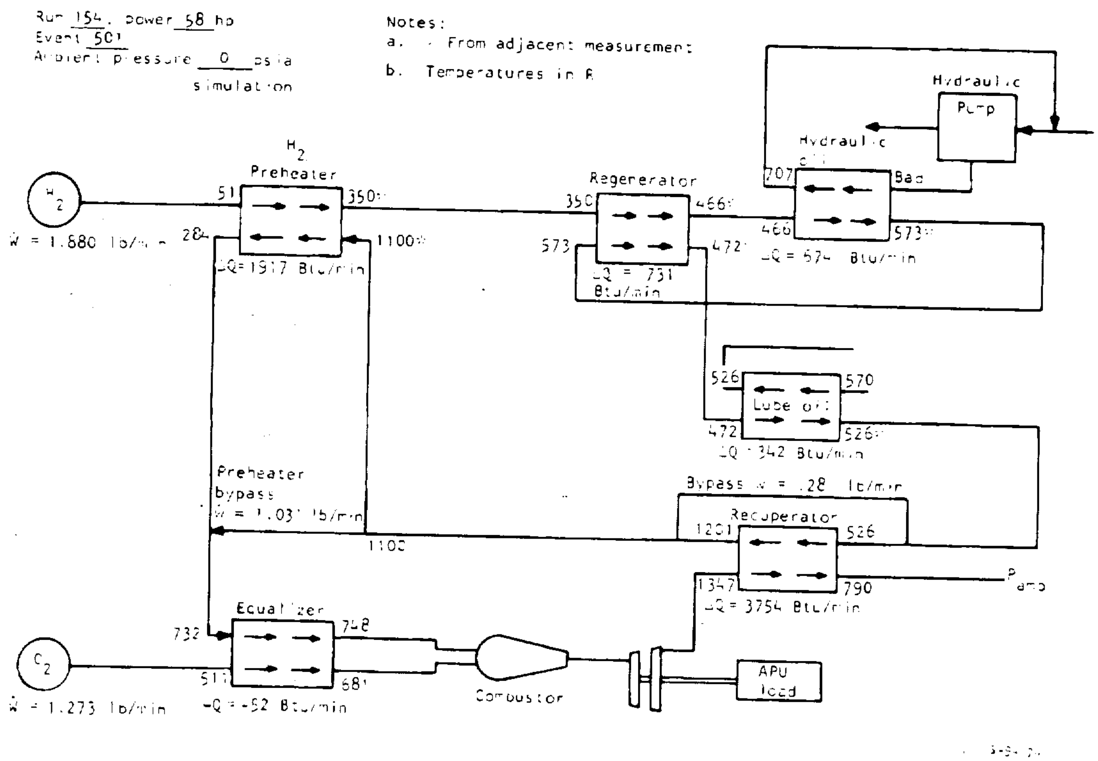

Figure 48.--Schematic of H_2-O_2 APU Showing Temperature Distribution (Event 501).

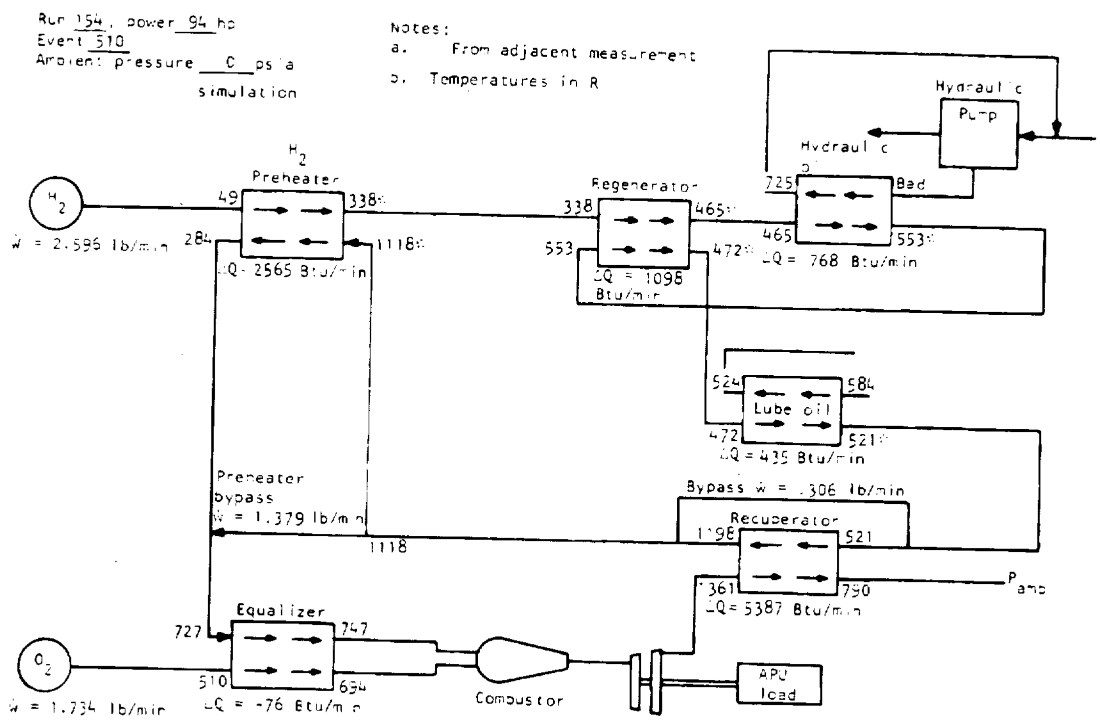

Figure 49.--Schematic of H_2-O_2 APU Showing Temperature Distribution (Event 510).

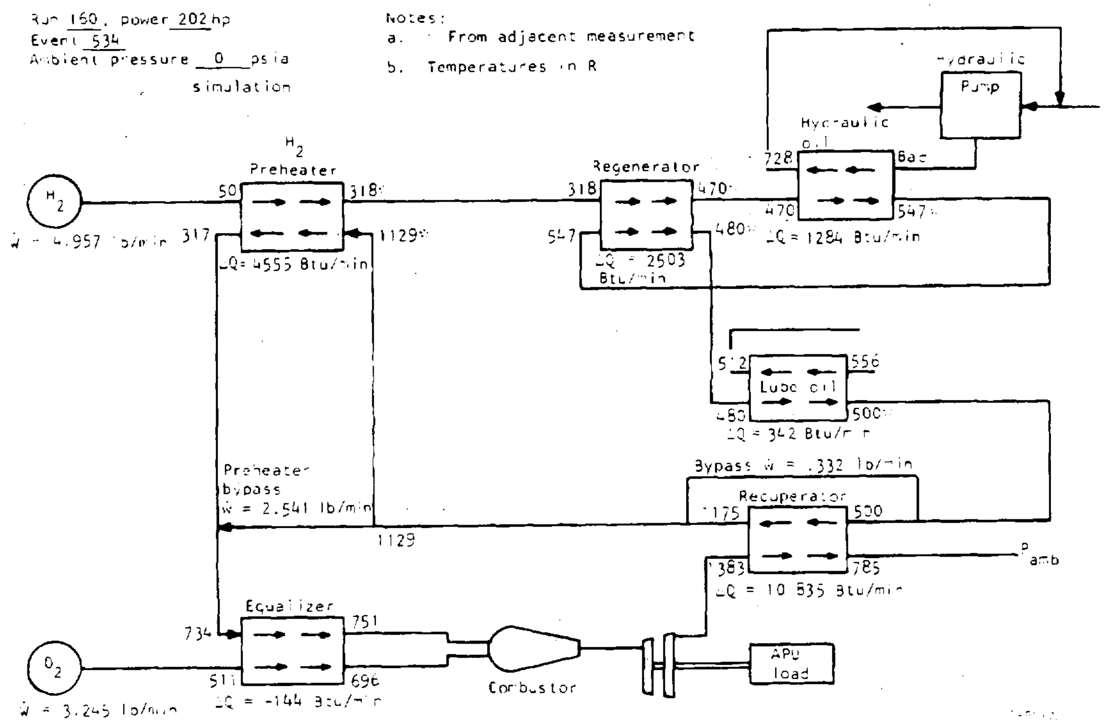

Figure 50.--Schematic of H_2-O_2 APU Showing Temperature Distribution (Event 534).

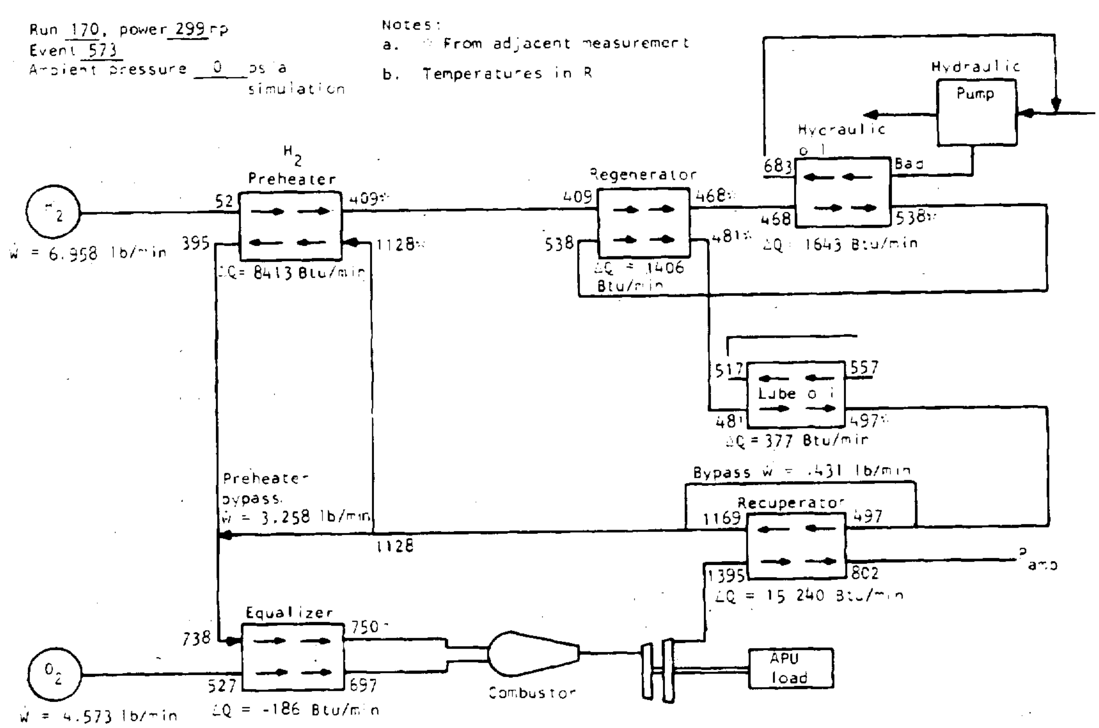

Figure 51.--Schematic of H_2-O_2 APU Showing Temperature Distribution (Event 573).

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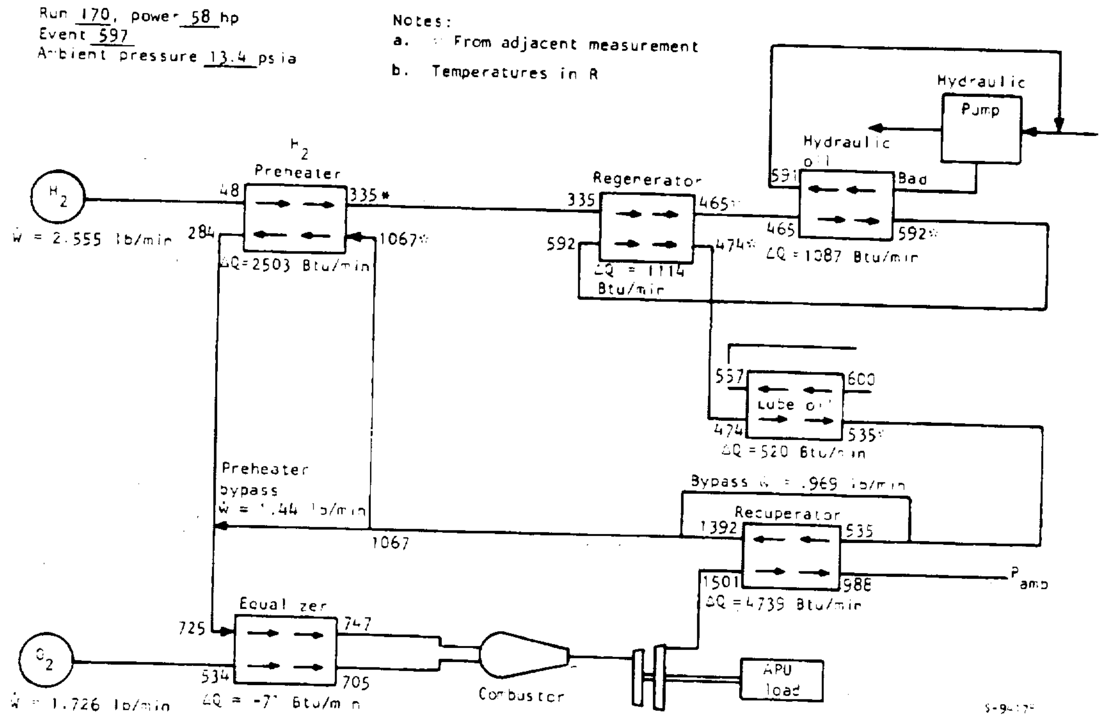


Figure 52.--Schematic of H_2-O_2 APU Showing Temperature Distribution (Event 597).

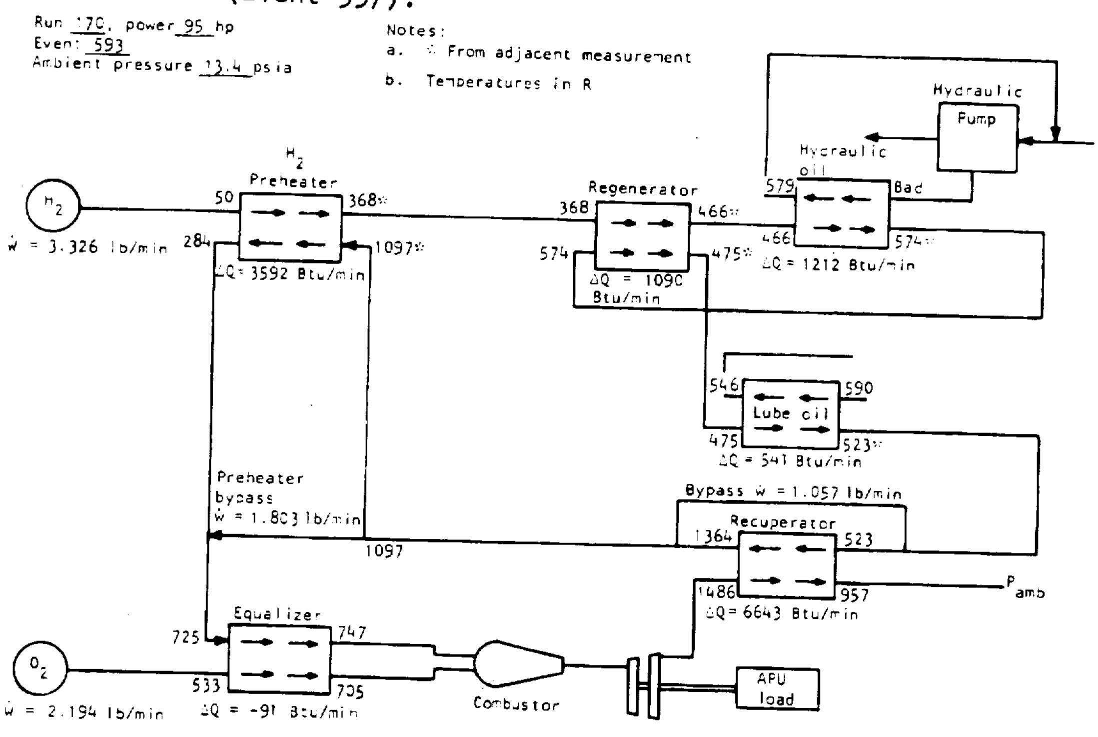


Figure 53.--Schematic of H_2-O_2 APU Showing Temperature Distribution (Event 593).

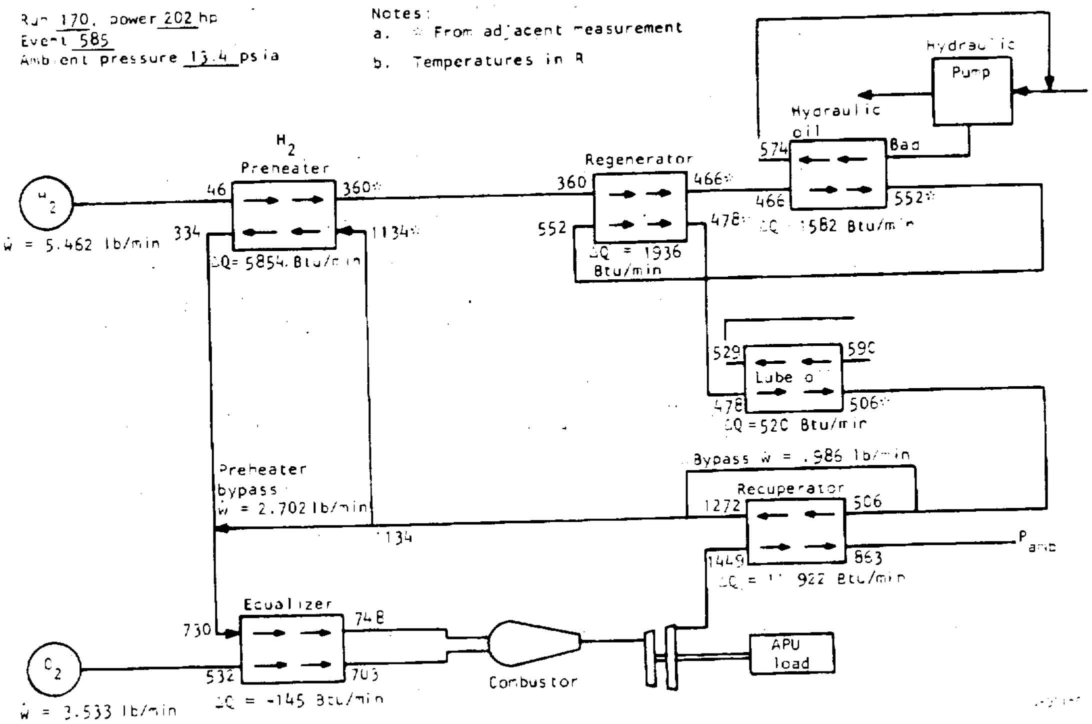


Figure 54.--Schematic of H_2-O_2 APU Showing Temperature Distribution (Event 585).

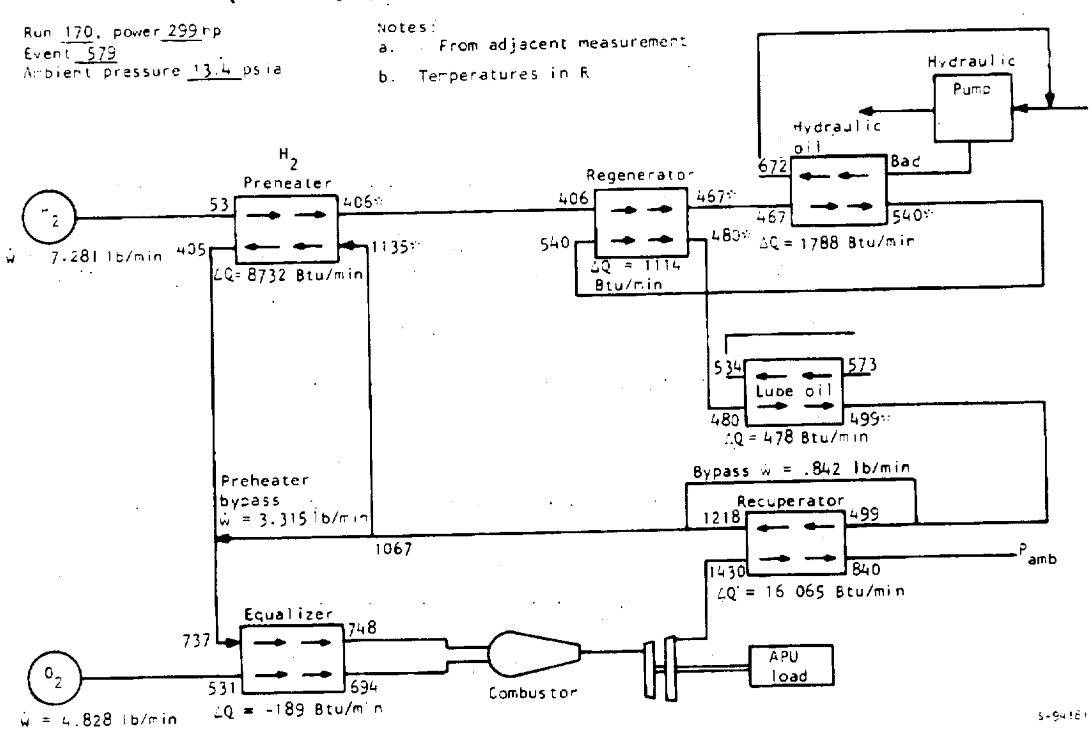
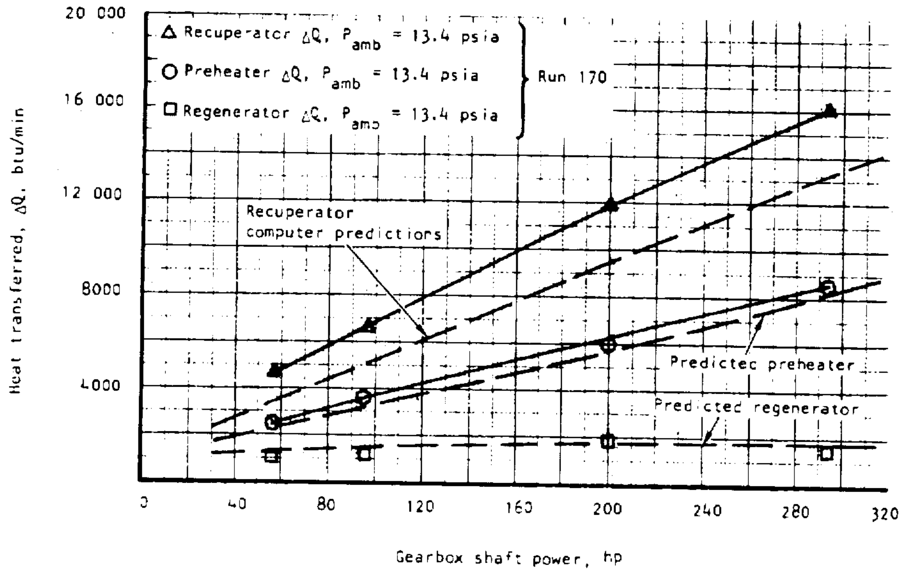


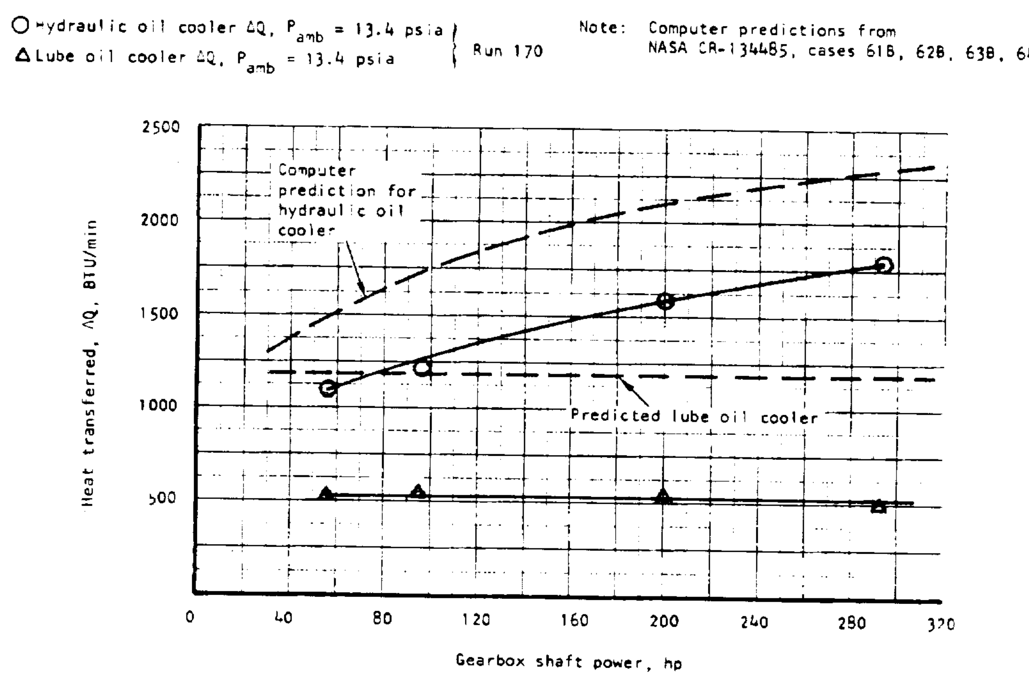
Figure 55.--Schematic of H_2-O_2 APU Showing Temperature Distribution (Event 579).



Note: Computer predictions from NASA CR-134485, cases 61B, 62B, 63B, 64

S-94196

Figure 56.--H_2-O_2 APU Heat Exchanger Data.



S-94165

Figure 57.--H_2-O_2 APU Heat Exchanger Data.

cooler, was expected to be different. However, in general, the heat exchanger performance was in good agreement, with values in the preheater and regenerator heat transfer almost identical to predictions. In the recuperator, the heat transferred was about 35 percent more at the low power of 58 hp and 20 percent more at 300 hp. The lube oil cooler transferred about one-half predicted value or about 500 Btu/min independent of the power level as expected. The hydraulic oil cooler had about 25 percent less heat transferred than the original computer predictions to a maximum of 1800 Btu/min at 300 hp.

To obtain comparisons with hot hydraulic oil operation, data at 300 hp and about 200 hp were used. Major differences with ambient hydraulic oil operation occurred mainly in the hydraulic oil cooler and lube oil cooler, with minor variations in the preheater, regenerator, and recuperator performance as shown in figs. 58 and 59. With hot hydraulic oil, the lube oil cooler transferred about 300 Btu/min or 60 percent of what it did with ambient hydraulic oil. On the other hand, the hydraulic oil cooler transferred about twice as much heat than with ambient hydraulic oil operation to a maximum of 3700 Btu/min at 300 hp.

As stated above, the equalizer performance was below predicted. The equalizer was unable to raise the oxygen temperature within 25 R of the hydrogen temperature as desired. Instead, oxygen gas stabilized about 50 to 60 R lower than the hydrogen temperature of 750 R.

It was previously mentioned that for the plots of figs. 56 through 59, cold side temperatures were used for ease of presentation. The hot side values also were calculated and compared favorably with cold side values as shown in table 12 for the 300-hp setting in run 180, as an example. The total heat transferred with hot hydraulic oil at approximately 300 hp was 29 500 Btu/min as calculated from the cold side and 30 300 Btu/min as calculated from the hot side, or less than 3-percent variation. For comparison, the predicted total heat transfer at 315 hp (case 59, ref. 2) was 25 600 Btu/min. For fair comparisons of test data with computer predictions, variations in inlet H_2 and O_2 temperatures and flows and bypass flows in the preheater and recuperator would have to be accounted for. Thus, in the discussion entitled: Test Data Comparison with Analysis, test data were simulated in the H_2-O_2 APU system analysis computer program.

Overall performance: In the APU-T system tests, steady-state data was obtained from power ranges of approximately 45 to 350 hp both at sea level and space simulation operation. Correlations of propellant flow (H_2 and O_2) versus hydraulic flow rate were made in figs. 60 and 61 and compared with predictions for all of the steady-state data available from the entire test series. Data with both steam ejectors off and on was presented in figs. 60 and 61, respectively. The data was run at a range of H_2 temperatures from ambient to cryogenic. Propellant flow was fairly linear as predicted, but higher. Considering the many test points used in the plot at various operating H_2 temperatures, the data correlation was excellent. In figs. 62 and 63, combustor chamber pressure also was plotted versus hydraulic flow for the two altitude simulations. That data also was fairly linear as predicted, with chamber pressures running slightly higher than expected.

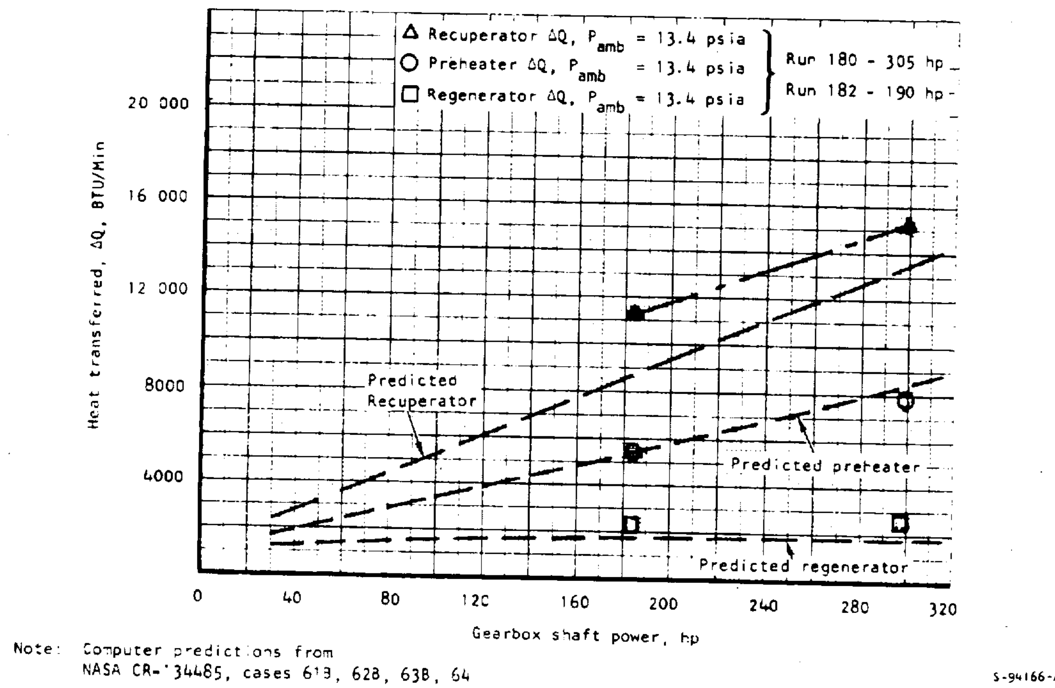


Figure 58.--H_2-O_2 APU Heat Exchanger Data.

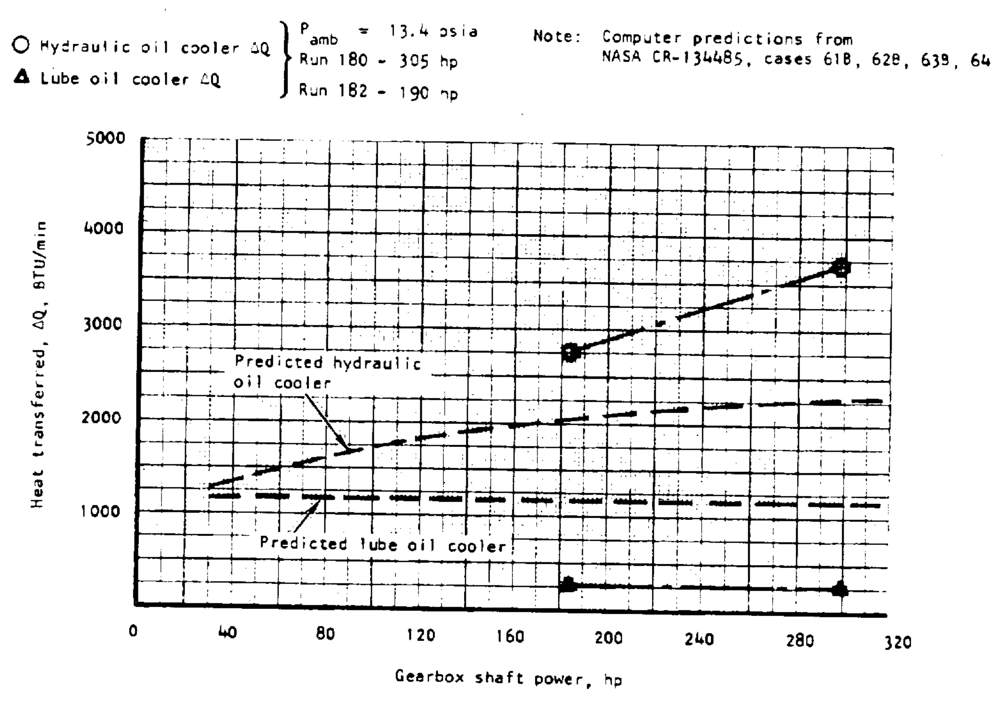


Figure 59.--H_2-O_2 APU Heat Exchanger Data.

TABLE 12

COLD SIDE AND HOT SIDE HEAT TRANSFER
RUN 180, EVENT 631, HP = 305

	Flow, lb/min	T_{in}, R	T_{out}, R	ΔQ Btu/min
Preheater-cold side	7.537, H_2	53	364	7971
hot side	3.676, H_2	1084	366	9100
Regenerator-cold side	7.537, H_2	364	469	2653
hot side	7.537, H_2	615	496	3016
Hydraulic-cold side	7.537, H_2	469	615	3713
Oil cooler hot side	89.48 (oil)	743	668	4361
Lube oil-cold side	7.537, H_2	496	507	281
Cooler hot side	12.095 (oil)	550	526	125
Recuperator-cold side	5.750, H_2	507	1263	15102
hot side	12.492 (combusted H_2-O_2)	1427	909	13900
Equalizer-cold side	7.537, H_2	733	749	---
hot side	4.891, O_2	518	688	-200

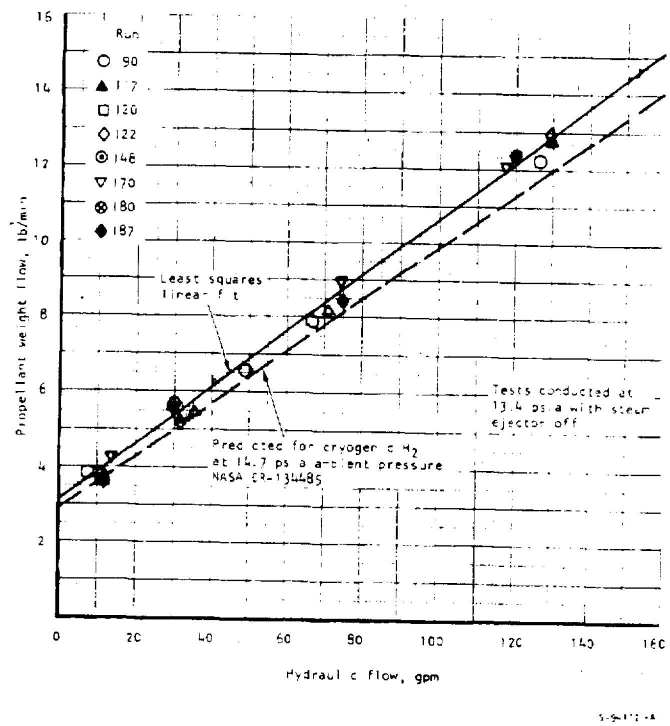


Figure 60.--H_2-O_2 APU Propellant Weight Flow at Ambient Back Pressure.

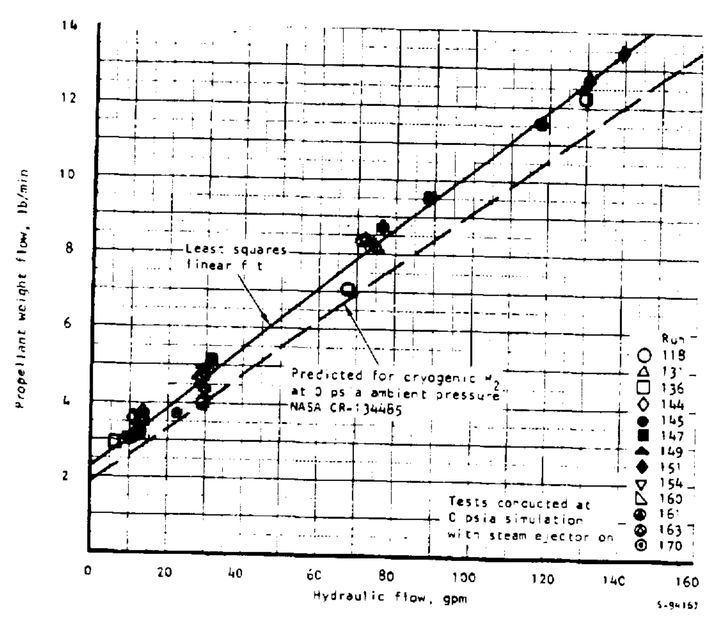


Figure 61.--H_2-O_2 APU Propellant Weight Flow at Space Simulation.

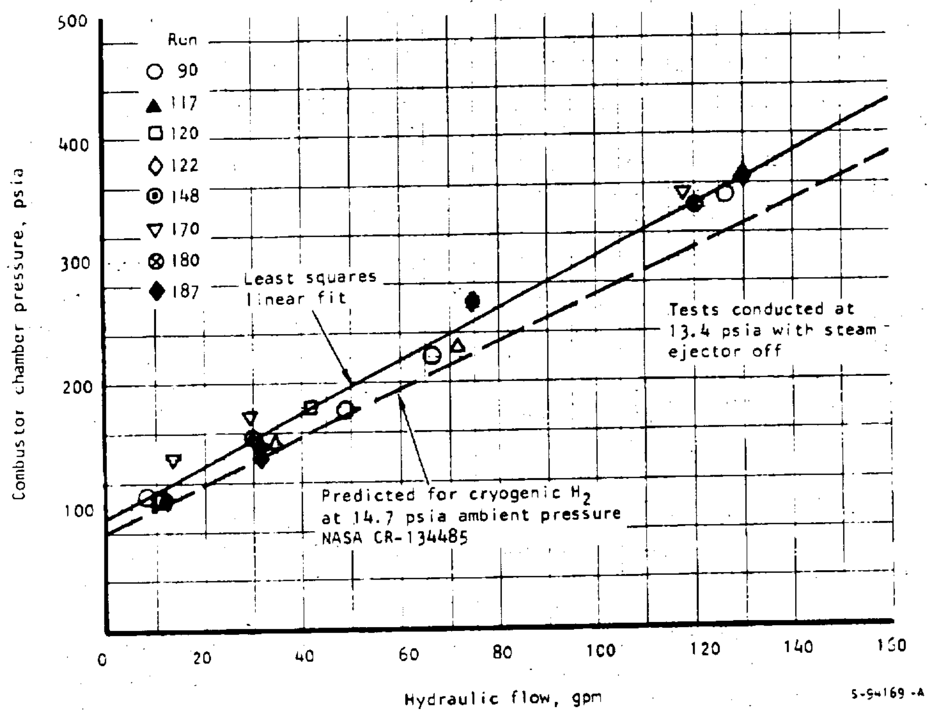


Figure 62.--H_2-O_2 APU Chamber Pressure at Ambient Back Pressure.

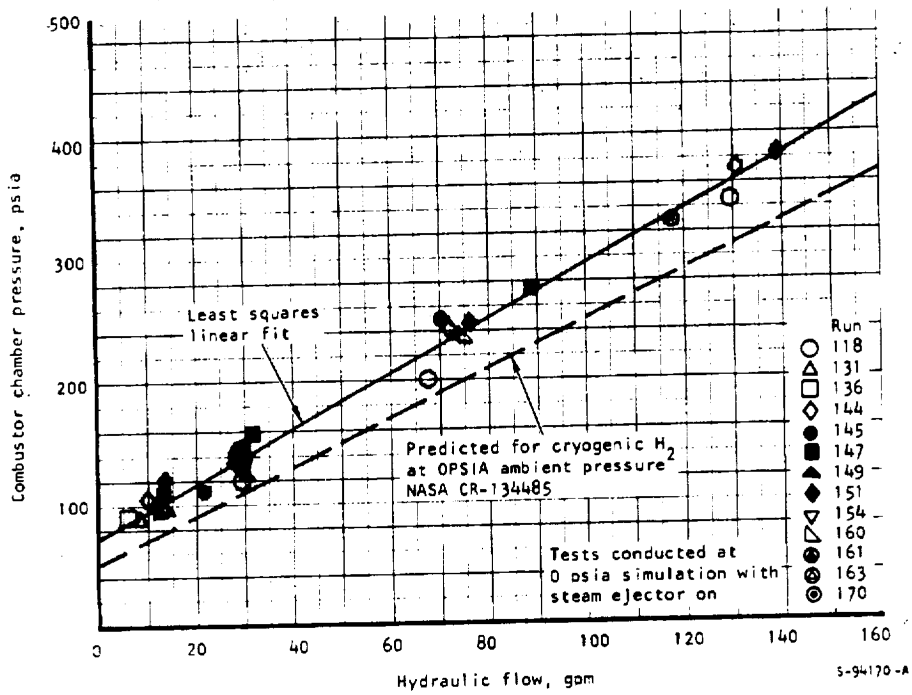


Figure 63.--H_2-O_2 APU Chamber Pressure at Space Simulation.

The close agreement of pump performance before and after repair, as shown in figs 60 and 62, indicates that performance anomalies incident to pump damage were confined to the run in which the damage was detected. Because of the linearity and small data scatter shown in the curves of figs. 60 through 63, overall APU performance was extrapolated, both to lower and higher power levels than tested, with a high degree of confidence. For the overall APU performance in terms of specific propellant consumption shown in figs. 64 and 65, test data was extrapolated to a low power setting of 30 hp and to a high power setting of 400 hp. The specific propellant consumption was higher than predicted for the two altitude simulations. This would be expected from the previous correlations of propellant flow and chamber pressure. Both at sea level and space simulation, the APU appeared to be operating about 10 percent higher than predicted in specific propellant consumption at the high horsepower levels. At the low horsepower levels, there was more data scatter, but agreement with predictions at ambient back pressure in particular (fig. 64) was excellent.

The close agreement between predictions made prior to APU-T system tests in ref. 2 with different operating flow rates and temperatures, and APU system tests demonstrated the validity of the predictive techniques employed.

The lowest power level reached in the tests was about 45 hp. To throttle back the APU-T to a lower idle power level, the electronic stops would have to be set at their minimum level. Then propellant flows would be reduced until changes in turbine inlet temperature or turbine speed were observed.

The APU-T back pressures for typical test runs at both 13.4 psia ambient pressure and space simulation are shown in fig. 66. Test results compared favorably with predictions. It is particularly interesting to note that in the space simulation case the two steam ejectors were fully opened and no changes in valve areas were made during a run. Thus, predicted back pressures were attained without ejector flow manipulation.

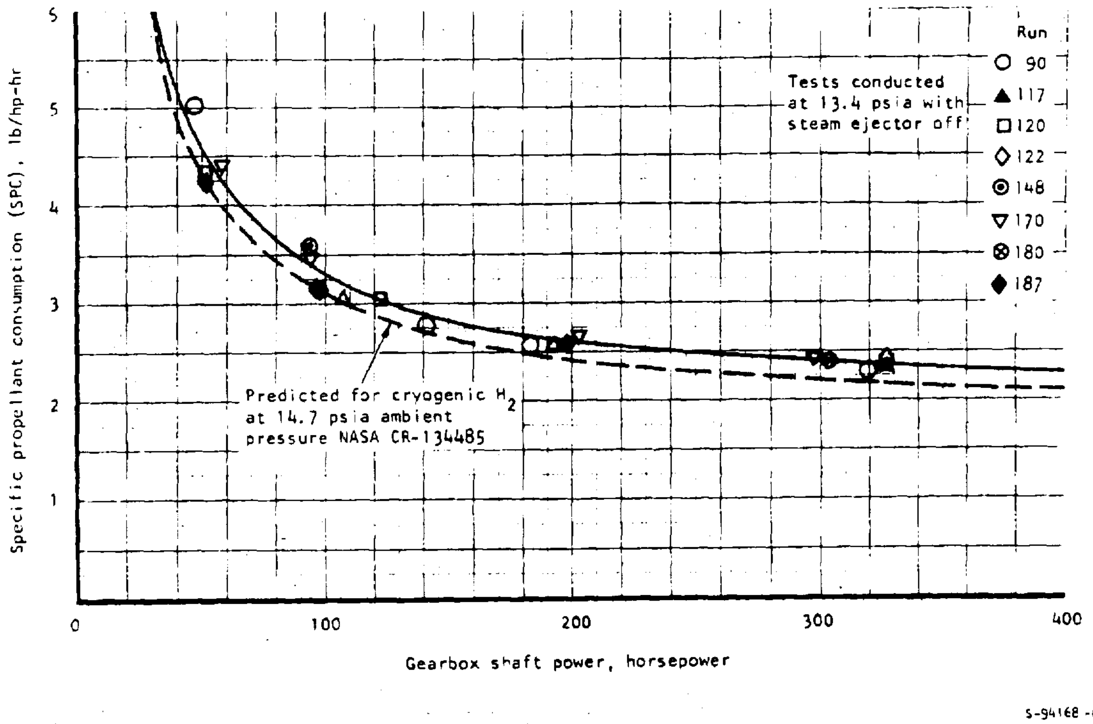


Figure 64.--H_2-O_2 APU Overall Performance at Ambient Back Pressure.

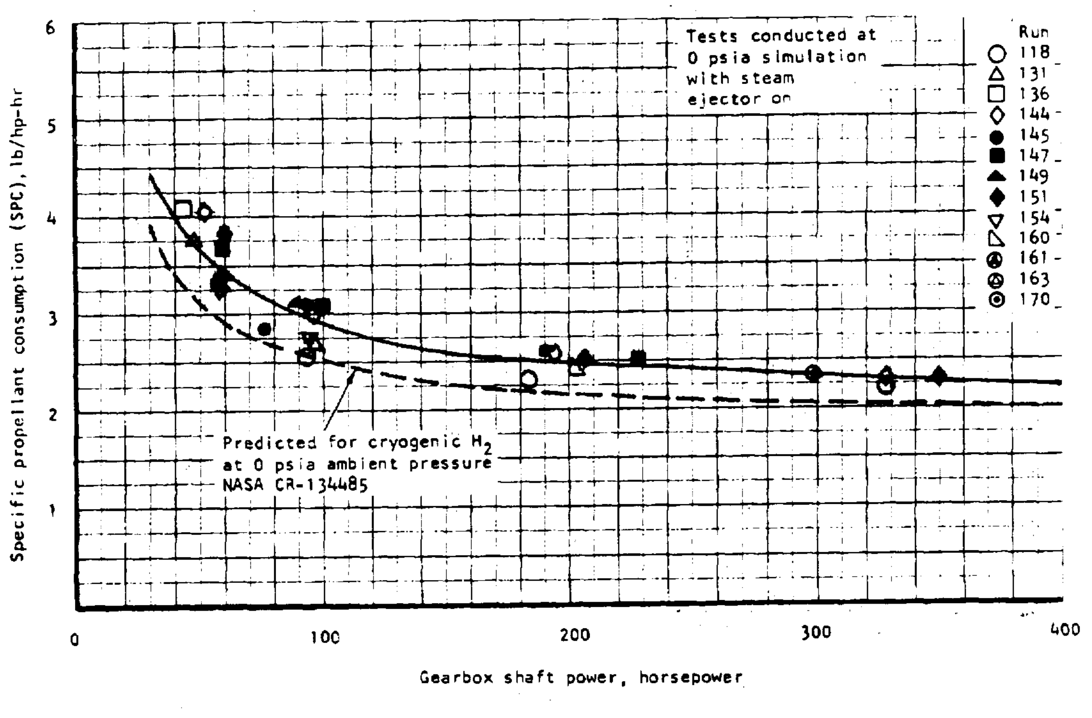


Figure 65.--H_2-O_2 APU Overall Performance at Space Simulation.

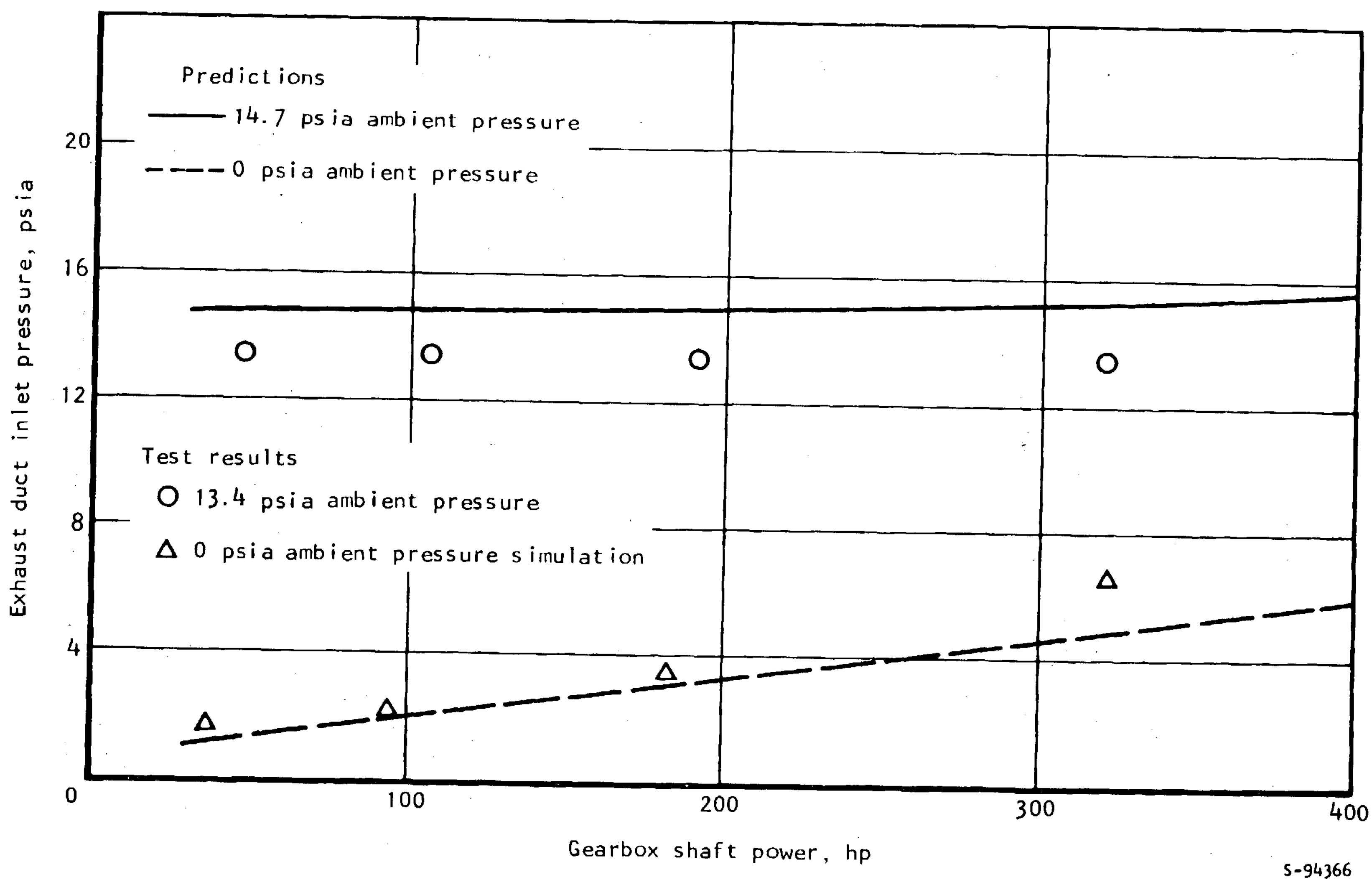


Figure 66.--H_2-O_2 APU Back Pressure.

ANALYSIS OF TEST RESULTS

Combustor

As evidenced from results of component and APU-T system tests, the hydrogen-oxygen combustor provided efficient and stable combustion over a wide range of chamber pressures. Combustor operation, at the fixed oxidizer-to-fuel ratio in the system tests, was essentially independent of chamber pressure. For the majority of tests, no problems with combustor ignition were experienced. In some of the early system testing, problems were encountered with spark plug fouling that prevented lightoff or, in some cases, caused a hard lightoff. This problem was corrected by inspection and replacement of spark plugs when they appeared to be fouled. The spark plugs used were automotive-type and were used in the interest of cost reduction. The main problem that did occur in the APU-T tests was melting of the spark plug tip.

In the prototype combustor tests and the control subsystem tests, no problem occurred with the spark plugs. In the APU-T system tests with the turbine installed, a spark plug tip was melted in the initial tests. Melting was caused by a leak that appeared to develop at the spark plug seal. The combustor was repaired and modified to better position the seal concentric with the plug axis. However, the melting reoccurred. Analysis of the hardware and test data indicated that the cause of the burnout was not the same as the one previously experienced because the spark plug seal was virtually intact. It was concluded that the spark plug was breathing the hot products of combustion of oxygen and hydrogen from the combustor which mixed with the oxygen in the plug and burned. The electrode end of the plug then became hot enough to initiate an oxygen fire. To prevent a reoccurrence, the combustor was modified from its original design. A separate line was used to feed propellant to the spark plug rather than directly from the combustor oxygen manifold. Additionally, two valves were used to sequence gaseous oxygen or hydrogen to the spark plugs. Gaseous oxygen was injected during lightoff and then gaseous hydrogen was injected through the spark plug during steady-state operation. This was done to provide cooling and prevent combustible mixtures within the plug. A nitrogen purge was injected between oxygen and hydrogen flows.

The above changes were satisfactory for the majority of APU-T system tests conducted after the modifications were made. Near the end of the system test program, however, the spark plug tips began to melt, as shown in fig. 67. The spark plug gas supply valves were checked for leaks or improper sequencing and found to be in satisfactory condition. Several checkout runs were made to ensure proper gas supply to the plugs. Plug tip melting still reoccurred.

After testing had been terminated, the combustor was disassembled for inspection. Inspection showed melted areas on the spark plug boss. Also, it was observed that the oxygen injectors were not concentric with the hydrogen injectors as in the original assembly. The oxygen injectors were distorted and discolored by heating.

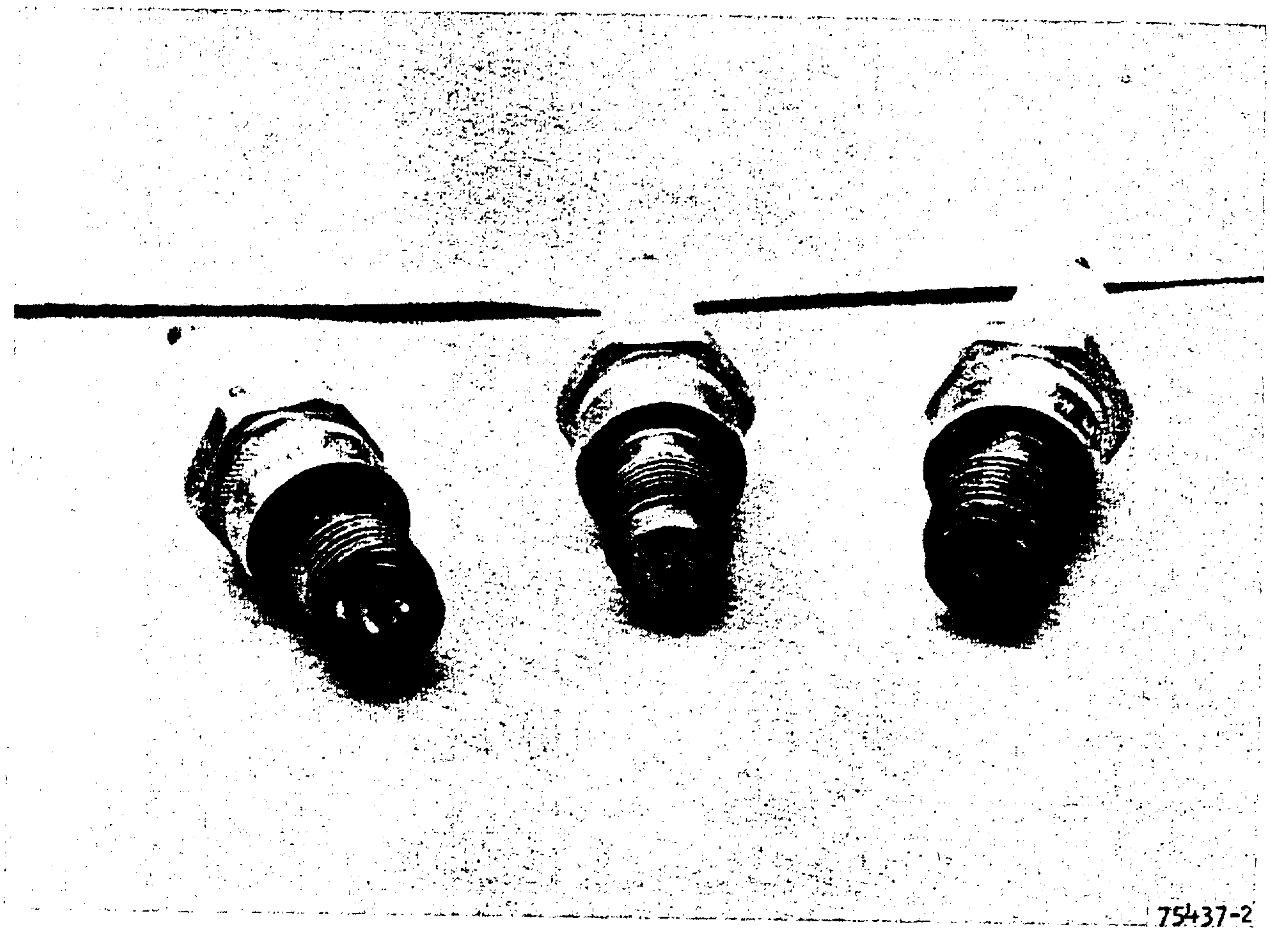


Figure 67.--Spark Plug Burnout Damage, Showing Melting of Plug Tips.

The case to liner gap indicated in fig. 68 as H_2 exit gap, also had increased about 50 percent because of distortion of the combustor case. This causes the primary zone temperature to increase and subjects the spark plug to a higher temperature environment. The rationale for this is as follows:

(1) The hydrogen delivered to the combustor bypasses the primary zone through the cooling jacket (40 percent of total hydrogen flow).

(2) The total combustor hydrogen flow is composed of the sum of the primary and bypass flows. The total flow is fixed by the power demand and the turbine inlet temperature.

(3) Therefore, an increase in the bypass flow causes a decrease in flow in the primary zone. This results in a change in O/F ratio that gives a higher primary zone temperature.

(4) The increase in the case to liner gap, found during inspection of the combustor, causes an increase in the bypass flow because the gap area controls flow.

The design primary zone average temperature is 2660 R, which is about 500 degrees below the melting point of the plug. If the primary zone flow were reduced by about 30 percent, the average gas temperature would exceed the melting temperature of the plug. Local temperature could exceed the average. Therefore, it is concluded that the distortion of the case and associated 50-percent increase in flow area can explain the plug melting problem and the distortion of the injectors.

The spark plug melting problem is summarized as follows:

(1) No spark plug problems occurred during combustor development or subsystem testing.

(2) When the turbine was added for the system tests, plug melting problems were first encountered.

(3) The problem was caused by an oxygen fire within the plug. The fire was fed by hydrogen breathing into the plug because of pressure fluctuations in the combustor. These fluctuations were created by the control valve modulation required to hold a constant turbine speed.

(4) The problem was solved by eliminating the oxygen supplied to the plug during steady-state operation. Oxygen was used for startup only.

(5) Spark plug tip melting reoccurred near the end of the program after about 9 hr operation.

(6) Inspection of the combustor revealed that the injectors and the area surrounding the spark plug had been exposed to high temperature.

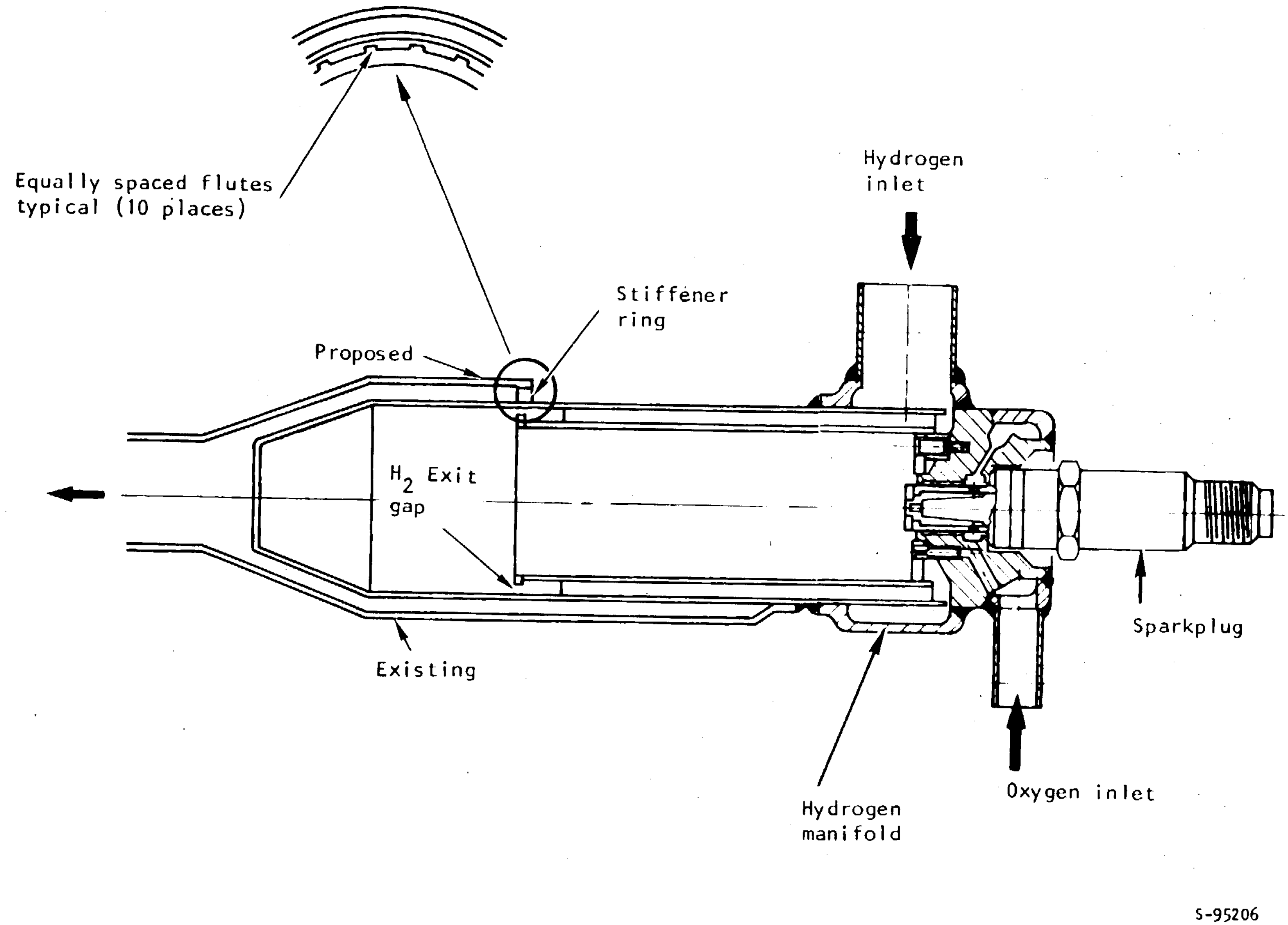


Figure 68.--Proposed Final Combustor Design.

(7) Distortion of the combustor case caused a reduction in hydrogen flow through the primary zone of the combustor. This increased gas temperature around the injectors and plug tip.

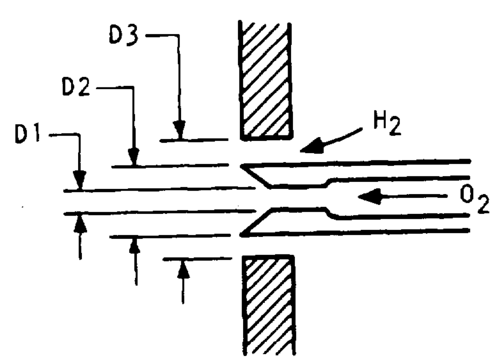
The test program was terminated before an attempt could be made to demonstrate the solution of the plug problem. The following two modifications are required:

(1) The combustor case should be reinforced in the region of the cooling jacket exit, as shown in fig. 68. This will prevent the jacket exit area from changing because of case distortion. The required primary zone hydrogen flow can be properly metered then to prevent high temperatures. Also, the liner exit lip should be fluted to maintain concentricity between the liner and the case. The modifications are defined in fig. 68. The existing copper lip was fluted when the combustor was disassembled for repair at the start of the system tests. This was done by coining the existing lip to form the flutes. However, some of the flutes were worn away because of vibration and relative movement between the lip and case. Therefore, the lip should be fabricated from steel to minimize wear.

(2) Oxygen should be supplied to the spark plug continuously during startup and steady-state operation. This will eliminate the need for the sequencing valves to supply the nitrogen purge and hydrogen to the plug. The supply pressure to the plug and the injectors should be increased to prevent ingestion of the combustion gas during pressure fluctuations. The areas of the injectors and the spark plug exit must be decreased to obtain a higher supply pressure. Also, the spark plug metering orifice should be removed to provide a high pressure in the plug.

The injector dimension modifications to double the injector velocity head follow. These are recommended for the next build. Also listed are the flow conditions consistent with the combustor design summary of page 6-3 in the APU Design Report (ref. 1).

Injector dimensions



O_2 Injector

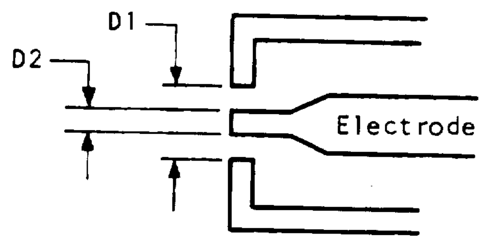
	Total area in.^{2}	Velocity head, psid	Injector velocity, ft/sec	D1, in.
Existing	0.0169	24	335	0.052
Recommended	0.012	48	456	0.043

H_2 Injector

	Total area, in.^{2}	Velocity head, psid	Injector velocity, ft/sec	D2, in.	D3, in.
Existing	0.057	26.6	1380	0.125	0.157
Recommended	0.040	53.2	1905	0.125	0.148

The existing spark plug gap is 0.051-in. with a 0.10-in. dia electrode. The required gap with the control orifice removed and full O_2 manifold pressure in the plug is prohibitively small (0.0038-in). Therefore, the electrode diameter should be reduced to increase this small gap width. The following table compares the existing and recommended spark plug jet characteristics.

Spark plug jet characteristics



	Area, in.^{2}	Flow, lb/sec	Jet velocity, ft/sec	Gap, in.	D1, in.	D2, in.
Existing	0.0083	0.008	71	0.15	0.130	0.10
Recommended	0.00157	0.010	335	0.010	0.060	0.040

Turbine

The APU-T calculated turbine efficiency was about 4 to 8 points lower than the predicted value of 52 to 53 percent over the range of pressure ratios tested. In the first hot runs of the APU-T, it was determined that the knife-edge labyrinth shaft seal in front of the first-stage rotor was leaking gas. Although measurements were not taken to establish the amount of leaked gas, it appeared to be excessive. Calculations based on measurements after the test runs gave between 2.2 to 4.3 percent leakage of the total turbine flow. The design value was below 1 percent. The port that vents this leakage to the recuperator outlet was capped. By inference, the identical labyrinth seal between the first and second stages was also leaking.

There are multiple effects on turbine performance because of increased leakage:

(1) The leaking gas does not go through the wheels, therefore its work is totally lost.

(2) The leakage decreases the flow through the second-stage nozzle, and thus changes the pressure distribution and work outputs of the stages, reducing overall efficiency.

(3) The leakage flow increases the flow deviation angle of the nozzle jets, which increases the incidence loss.

As an order of magnitude, 1-percent flow leakage would have caused a loss of 1 percent in turbine efficiency. Based on calculated leakage, the lower turbine performance, therefore, was primarily a cause of seal leakage and this contributed to the higher specific propellant consumptions than predicted. To decrease flow leakage and thus improve turbine performance, the use of smaller cells in the honeycomb is recommended.

Heat Exchangers

The APU-T system heat exchangers performed as predicted with the exception of the equalizer. The equalizer had been performance-tested in component tests (Appendix A) and found to be deficient in meeting design requirements. The departure from design requirements on the oxygen side was attributed to an inadequate braze joint of the buffer fins to the surface of the plate. This created increased buffer zone resistance and caused the oxygen outlet temperature of the equalizer to be about 50 R lower than the hydrogen outlet of 750 R.

In general, test data agreed with predictions over the entire horsepower range, even though test and predicted inputs varied. Simulations of test conditions were made and are reported in greater detail in a later discussion, Test Data Comparison with Analysis. A comparison at a power level of 305 hp is shown in table 13. The agreement of the computer simulation with data obtained on both the hot and cold sides of the heat exchnagers was excellent.

TABLE 13

COMPUTER SIMULATION OF RUN 180, EVENT 631, HP = 305

Heat exchanger	ΔQ Btu/min		
	Computer simulation	Test data	Side
Preheater	7917	7971 9100	Cold side Hot side
Regenerator	2678	2653 3016	Cold side Hot side
Hydraulic oil cooler	3362	3713 4361	Cold side Hot side
Lube oil cooler	401	281 125	Cold side Hot side
Recuperator	13 404	15 102 13 900	Cold side Hot side
Equalizer	-244	-- -200	Cold side Hot side

The cooling capabilities of the hydrualic oil cooler and lube oil cooler also were examined. The APU system specifications for the hydraulic system were a heat sink capability of 5000 Btu/min at 400 hp. Testing with hot hydraulic oil operation was only conducted to the power level of 300 hp with hydrogen cooled to LH_2 temperatures. In fig. 58, the hydraulic oil cooler and lube oil cooler transferred about 4000 Btu/min at 305 hp. Extrapolating this data to 400 hp would indicate a heat sink capability for the hydraulic system of 4700 Btu/min.

System Analysis

The APU-T system was analyzed using a digital computer simulator. The simulation was capable of calculating either steady-state or transient solutions to the system and sizing and evaluating component performance for the complete system operating range.

The APU-T control design shown schematically in fig. 69 was mechanized in the simulator to verify stability and predict transient performance. The simulation has the capability of calculating the pressures and temperatures at each of the engine stations shown in the figure.

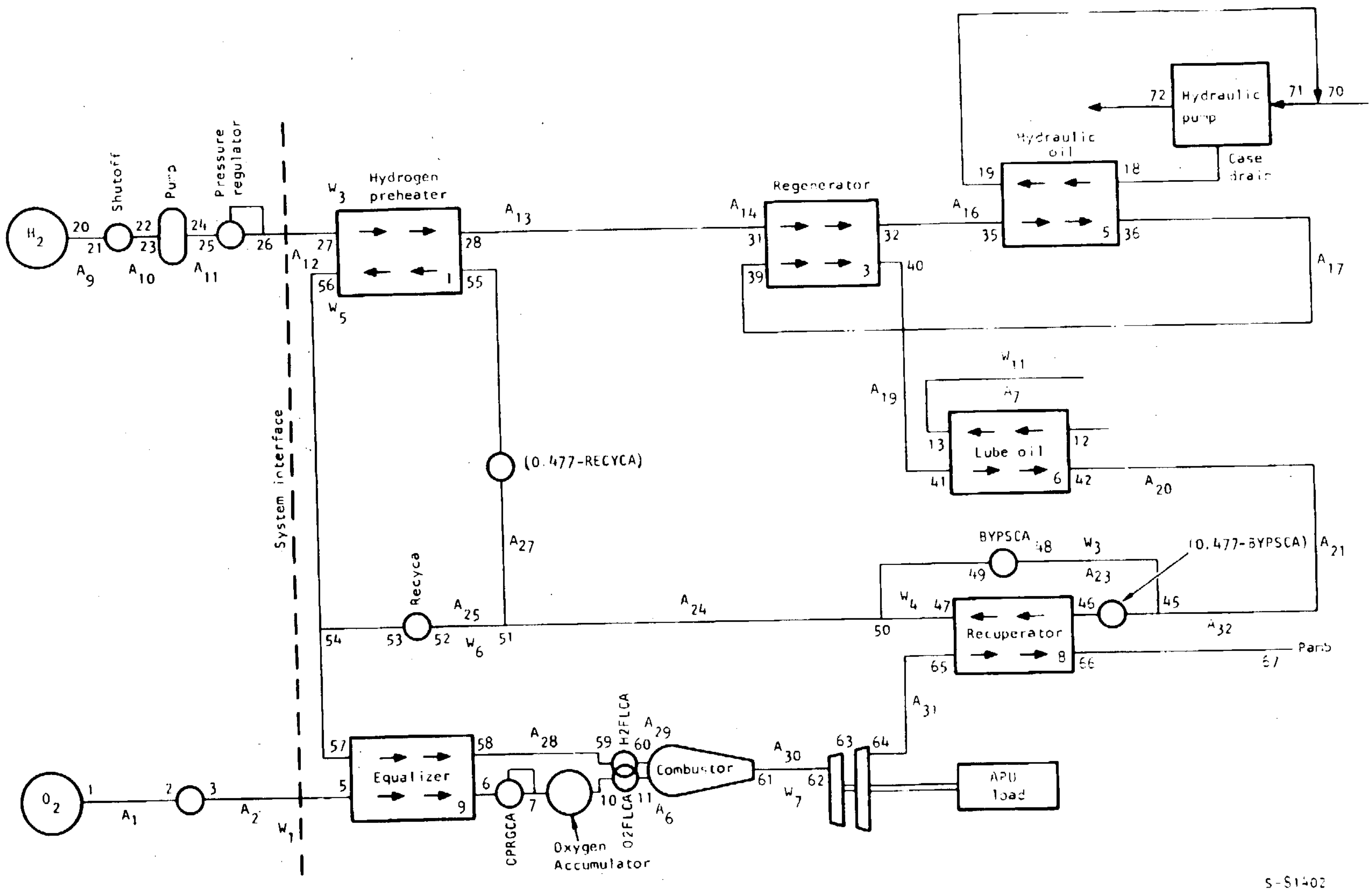


Figure 69.--H_2-O_2 APU Computer Program Notation.

A detailed writeup of the computer simulator was given in ref. 1. The following is a brief description of the computer program and its main functions.

The simulator is constructed by the use of a main subroutine that reads the control data cards. The data cards are of two types: (1) data to be used during a solution, and (2) solution types (bypass, no-bypass, design point, off-design). The mode for data (to be used during a solution) is used to define boundary conditions or to scale particular components within the system. Solution-type data are used to select the dependent relationships to be satisfied and the independent parameters to be manipulated to satisfy the dependent conditions.

The steady-state solutions are obtained by the use of the boundary specified by various data cards and the required conditions for the particular solution desired. The main subroutine then dimensions the matrix required for the solution and establishes the particular independent variables and dependent relations to be used during the solution. The next step is to call a subroutine that solves a set of algebraic equations using a modified Newtonian technique (NEWTON). This, in turn, calls an external subroutine, which is specified in its argument list to determine the algebraic relationships between the various independent and dependent variables. The dependent relations are written in a form that allows NEWTON to drive the dependent vector to the origin.

The two primary uses for steady-state solutions were: (1) initial design performance of the system, and (2) to set the initial conditions for a transient solution. The transient options of the APU simulator were developed for the controls analysis work. The options were used to identify the control transfer functions of the APU. The control verification and the dynamic performance parametric studies were used to establish the sufficiency of the various control systems and to study the effects of various components on the APU performance.

The valving (six valves) of the APU-T system was constrained in such a way that there were only four independent forcing variables in the system. The preheater bypass valve and the preheater series valve were programmed as complementary; that is, the area of the preheater bypass plus the area of the preheater series valve was a constant at 0.477 sq in. The same arrangement was used for the series and bypass valves relating to the recuperator.

The four independent engine variables were: (1) oxygen flow control, (2) hydrogen flow control valve, (3) preheater bypass valve, and (4) recuperator bypass valve, as shown in fig. 69. The four independent variables allowed control of four engine relationships. The four parameters selected were turbine speed, turbine inlet temperature, the temperature of the hydrogen as it enters the hydraulic oil cooler, and the temperature of the hydrogen as it enters the combustor.

The simulator was used to predict the steady-state performance of the system and to provide data to size the valves and heat exchangers. The cases were run and specific propellant consumption as a function of power level was predicted (ref. 2).

The system simulator provided data for scheduling T_{32} (hydrogen temperature at the inlet to the hydraulic oil heat exchanger) as a function of the lube oil temperature. This schedule was necessary for two reasons: (1) the temperature of the hydrogen on both sides of the regenerator is about equal as it exists, because of the parallel flow design, and (2) at high altitude the hydrogen flow decreases because of the increased pressure ratio across the turbine. The total effect is to reduce the hydrogen cooling available to the lube oil. To improve cooling, the temperature is reduced from 460 to 400 R from the regenerator as the lube oil temperature rises from 650 to 700 R. This effect comes into operation only at a long-duration idle at high altitude.

The final use of the steady-state operation of the simulator is to select an operating point that will be used for the starting point of a transient. The steady-state solution provides the initial conditions for the differential equations that describe the dynamic portion of the system. The valve positions that result in the steady-state solution provide data needed to initialize the differential equations in the control.

The first use of the transient capability of the computer simulation was to identify the control transfer functions for the APU. The method used to identify the transfer functions was to start from steady-state and to step one of the control valves 5 percent, then plot data on the control parameters. Then a rate of steepest descent technique was used to adjust the parameters of a differential equation of the proper form to yield a minimum error.

The control system design was based on the transfer functions that were derived. The control system was mechanized on the computer in the same form as the hardware was to be built. This enabled the system performance with the control system to be predicted. The primary information derived was the stability margin of the control system during large transient disturbances. The primary disturbance is a load change of the hydraulic system.

Test Data Comparison With Analysis

The APU-T system test heat exchanger performance and overall performance was compared with computer predictions in the previous sections. The APU-T predicted performance was taken from the computer runs tabulated in ref. 2 as computer cases 56B, 57B, 58B, 59, 60, 61B, 62B, 63B, 64, and 65. The first five cases were run at 0 psia ambient pressure, the last five, at 14.7 psia ambient pressure. The computer predictions compared favorably with test results.

These computer cases were not an exact simulation of APU-T test conditions, although they were close. For instance, tests were made with ambient oxygen instead of cooling it to 300 R as run in the computer cases. Also, the equalizer outlet temperature was 750 R for both hydrogen and oxygen for the majority of computer cases, whereas in the APU-T tests, the oxygen outlet temperature was 50 to 60 R lower at 690 to 700 R. Hydraulic oil and lube oil temperatures also were different in the APU-T tests as well as ambient pressure (0 psia simulation and 13.4 psia for sea level operation). Therefore, an attempt was made to simulate more closely the APU-T test conditions.

An exact simulation of the APU-T tests would have required major modifications to the computer program to account for different component performance than originally programmed. Simple modifications were made to the computer program so that all of the following test conditions could be input:

(1) Hydraulic oil inlet temperature at the hydraulic oil cooler

(2) Lube oil inlet temperature at the lube oil cooler

(3) Hydrogen inlet temperature on the cold side at the hydraulic oil cooler

(4) Hydrogen and oxygen initial temperatures and pressures

(5) Ambient pressure

(6) Hydrogen inlet temperature to the combustor

(7) Test power level

Computer simulations were made primarily for temperature comparisons at each of the stations in the APU to determine how closely heat exchanger performance was predicted. The test results from run 180, event 631, at a power level of 305 hp, was the first case simulated in table 14. Test temperatures and test heat transfer were also shown in this table for ease of comparison. The agreement with test results was excellent. Simulations also were made for the heat transfer data from runs 154, 160, and 170 previously shown. These computer runs are shown in tables 15 through 22. Unfortunately, the hydraulic oil inlet temperature to the hydraulic oil cooler was incorrect so this value had to be guessed in the simulations. Nevertheless, the overall agreement with test results was fairly good over the power range from 58 to 300 hp. The agreement was better at higher power levels as a result of more stabilized temperatures.

The good agreement between test and computer-predicted temperatures at the various SSAPU stations showed that the heat exchanger performance could be closely simulated. These simulations indicate that overall heat exchanger performance for the complete system operating range could be predicted with a high degree of confidence by use of the computer program.

To utilize the simulator for scaling the APU up or down in power, the components would have to be resized to meet system requirements. The sizing of the components would require that the nonlinear effects of the components be used, including major second-order component effects within the system.

TABLE 14

SIMULATION OF RUN 180 EVENT 631

GARRETT * AIRESEARCH MANUFACTURING DIVISION LOS ANGELES CALIF.

03 MAR 75 17102834

* CONDITION * BYPASS AMBIENT PRESSURE 13.41 PSIA.

HYDRAULIC POWER	260.00	GEAR BOX LOSS	20.00		FIRST STAGE POWER	162.97	SPE	6.178	AMA	3.39
HYDRAULIC PUMP	44.86	LUBE PUMP	4.00		SECOND STAGE	169.89	U/P	.082		
TOTAL GEAR BOX	304.86				TOTAL TURBINE	332.86	PT EXIT	13.499		

TURBINE INFORMATION

FLOW	11.004	PRESSURE	500.95	15.74	EFFICIENCY 1ST	.443	A1	.1517	A3	.6300
SPECIFIC HEAT RATIO	1.357	TEMPERATURE	1960.0	1386.0	EFFICIENCY 2ND	.496	A2	.2335	A4	.6930
PRESSURE RATIO	19.38	ENTHALPY	.0	.0	EFFICIENCY TOTAL	.540	NCOT	40.	N	63000.

CONTROL VALVES

	PREHEATER BYPASS	RECUPERATOR BYPASS	O2 PRES REG	OXYGEN FLOW	HYDROGEN FLOW
TEMPERATURE	1096.37	514.52	746.27	746.27	750.00
PRESSURE IN	500.91	503.68	639.69	569.71	492.62
PRESSURE OUT	499.19	502.23	569.71	334.21	332.29
EFFECTIVE AREA	.23937	.00482	.00459	.00646	.04567
FLOW	3.721	.991	4.487	4.487	6.577

HX NO.		FLOW	IN PRESSURE	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.	TEST HEAT TRANS.
1	COLD SIDE	6.577	527.06	525.18	53.00	361.14	-52.8	1150.9	.295	7917.02 BTU/MIN	7971 BTU/MIN
	HOT SIDE	2.857	500.19	499.16	1098.37	320.61	3762.1	990.9	.744	6 PASS COUNT	9100 BTU/MIN
3	COLD SIDE	6.577	524.52	516.97	361.14	469.00	1150.9	1558.0	.429	2677.86 BTU/MIN	2653 BTU/MIN
	HOT SIDE	6.577	513.14	509.18	612.75	497.58	2069.1	1661.9	.458	6 PASS PARALL	3016 BTU/MIN
5	COLD SIDE	6.577	518.11	514.23	469.00	612.75	1558.0	2069.2	.525	3362.16 BTU/MIN	3713 BTU/MIN
	HOT SIDE	57.000	200.00	197.90	745.00	638.34	.0	.0	.382	4 PASS COUNT	4361 BTU/MIN
6	COLD SIDE	6.577	508.72	504.66	497.58	514.52	1661.9	1722.9	.323	401.29 BTU/MIN	281 BTU/MIN
	HOT SIDE	28.500	200.00	195.85	550.00	517.63	.0	.0	.614	4 PASS COUNT	125 BTU/MIN
8	COLD SIDE	5.587	503.33	502.23	514.52	1201.92	1722.9	4122.2	.768	13404.38 BTU/MIN	15102 BTU/MIN
	HOT SIDE	11.004	15.44	14.12	1386.84	621.00	3265.3	2055.7	.648	2 PASS COUNT	13900 BTU/MIN
9	COLD SIDE	6.577	498.46	493.32	760.55	750.00	2588.6	2549.5	.044	-243.88 BTU/MIN	--
	HOT SIDE	4.487	853.60	839.69	518.00	746.27	106.0	160.2	.941	1 PASS PARALL	-200 BTU/MIN

EXHAUST DUCT	PT	PS	MACH
INLET	14.120	14.030	.092
EXIT	13.499	13.410	.096

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STATION	PRESSURE	TEMPERATURE	TEST TEMP.	ENTHALPY	STATION	PRESSURE	TEMPERATURE	TEST TEMP.	ENTHALPY
1	.000	.000		.000	41	508.719	497.579	496.	1661.569
2	.000	.000		.000	42	504.656	514.517		1722.879
3	.000	.000		.000	43	504.373	514.517		1722.872
4	.000	.010		.000	44	504.373	514.517		1722.872
5	853.600	510.000	518.	105.957	45	503.069	514.517	507.	1722.869
6	839.667	745.268		10[illegible].205	46	503.323	510.517		1722.855

TABLE 14 (Continued)

7	569.712	746.268	689.	.000	47	502.229	1201.922	1263.	4122.213
8	.000	746.268		.000	48	503.678	514.517		1722.804
9	.000	.000		.000	49	502.229	514.517		.000
10	569.712	746.268		.000	50	502.229	1098.370		3762.131
11	334.211	746.268		102.107	51	501.234	1098.370	1084.	3762.107
12	200.000	550.000	550.	.000	52	500.915	1098.370		3762.100
13	195.846	517.831	526.	.000	53	499.164	.000		.000
14	195.846	517.831		.000	54	499.164	760.554		2566.624
15	195.846	517.831		.000	55	500.187	1098.370		3762.082
16	200.000	743.000		.000	56	499.164	520.614	366.	990.884
17	200.000	743.000		.000	57	498.460	760.554	734.	2566.606
18	200.000	743.000	743.	.000	58	493.516	750.000	750.	2549.531
19	197.904	638.342	668.	.000	59	492.616	750.000		2549.516
20	.000	.000		.000	60	332.290	750.000		2546.149
21	.000	.000		.000	61	305.030	1960.000		6812.604
22	.000	.000		.000	62	304.952	1960.000	1944.	.000
23	.000	.000		.000	63	55.006	1644.939		.000
24	.000	.000		.000	64	15.739	1386.844		.000
25	.000	.000		.000	65	15.442	1386.844	1427.	3265.281
26	520.000	53.000	53.	-52.765	66	14.120	821.603	909.	2053.737
27	527.655	53.000		-52.771	67	13.499	821.603		.000
28	525.179	361.135		1150.882	68	.000	.000		.000
29	524.851	361.135		1150.881	69	.000	.000		.000
30	524.851	361.135		1150.881	70	.000	743.000		.000
31	524.523	361.135	364.	1150.880	71	.000	737.291		.000
32	516.972	469.000		1558.004	72	.000	756.138		.000
33	516.542	469.000		1557.998	73	.000	.000		.000
34	516.542	469.000		1557.998	74	.000	.000		.000
35	516.113	469.000	469.	1557.993	75	.000	.000		.000
36	514.235	612.746		2009.153	76	.000	.000		.000
37	513.688	612.746		2009.143	77	.000	.000		.000
38	513.688	612.746		2009.143	78	.000	.000		.000
39	513.141	612.746	615.	2009.133	79	14.030	.096		.000
40	509.183	497.579		1601.876	80	13.410	.098		1.000

TABLE 15

SIMULATION OF RUN 170 EVENT 579

GARRETT * AIRESEARCH MANUFACTURING DIVISON LOS ANGELES, CALIF.

* CONDITION * BYPASS AMBIENT PRESSURE 13.39 PSIA. 04 MAR 75 12148146

HYDRAULIC POWER	254.00	GEAR BOX LOSS	24.00	FIRST STAGE POWER	179.69	SFC	2.186	A**	3.59
HYDRAULIC PUMP	44.51	LUBE PUMP	4.00	SECOND STAGE	146.83	O/F	.683		
TOTAL GEAR BOX	298.51			TOTAL TURBINE	326.51	PT OUT	13.473		

TURBINE INFORMATION

FLOW	10.877	PRESSURE	299.69	15.61	EFFICIENCY 1ST	.443	A1	.1517	A3	.6300
SPECIFIC HEAT RATIO	1.357	TEMPERATURE	1960.0	1387.7	EFFICIENCY 2ND	.495	A2	.2335	A4	.6930
PRESSURE RATIO	19.20	ENTHALPY	.0	.0	EFFICIENCY TOTAL	.540	NDOT	-0.	N	63000.

CONTROL VALVES

	PREHEATER BYPASS	RECUPERATOR BYPASS	O2 PRES REG	OXYGEN FLOW	HYDROGEN FLOW
TEMPERATURE	1133.84	514.40	744.68	744.68	748.00
PRESSURE IN	514.99	518.05	839.80	569.75	506.95
PRESSURE OUT	513.06	516.21	569.75	328.45	326.44
EFFECTIVE AREA	.20628	.01453	.00451	.00634	.04292
FLOW	3.356	.343	4.415	4.415	6.462

HX NO.	FLOW	IN PRESSURE	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.	TEST HEAT TRANS.
1 COLD SIDE	6.462	540.57	538.01	53.00	394.51	-52.5	1279.8	.316	8609.48 BTU/MIN	8732.
HOT SIDE	3.106	514.29	513.06	1133.84	351.60	3885.7	1113.9	.724	6 PASS COUNT	-
3 COLD SIDE	6.462	537.33	531.88	394.51	467.00	1279.8	1550.9	.033	1751.43 BTU/MIN	1504.
HOT SIDE	6.462	526.51	522.97	561.75	485.85	1890.7	1619.5	.454	6 PASS PARALL	1469.
5 COLD SIDE	6.462	531.08	527.48	467.00	561.75	1550.9	1890.7	.479	2196.19 BTU/MIN	1788.
HOT SIDE	57.000	200.00	197.60	665.00	592.71	.0	.0	.365	4 PASS COUNT	BAD
6 COLD SIDE	6.462	522.55	518.95	485.85	514.40	1619.5	1722.7	.328	666.49 BTU/MIN	478.
HOT SIDE	28.500	200.00	197.01	573.00	520.11	.0	.0	.607	4 PASS COUNT	219.
8 COLD SIDE	6.118	517.47	516.22	514.40	1168.58	1722.7	4006.5	.749	13973.63 BTU/MIN	16065.
HOT SIDE	10.877	15.32	14.05	1367.74	787.89	3265.7	1981.0	.687	2 PASS COUNT	15300.
9 COLD SIDE	6.462	512.40	507.60	757.88	748.00	2577.5	2542.8	.044	-224.29 BTU/MIN	--
HOT SIDE	4.415	853.20	839.80	531.00	744.68	109.1	159.8	.942	1 PASS PARALL	-189.

EXHAUST DUCT	PT	PS	MACH
INLET	14.051	13.968	.092
EXIT	13.473	13.390	.095

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STATION	PRESSURE	TEMPERATURE	TEST TEMP.	ENTHALPY	STATION	PRESSURE	TEMPERATURE	TEST TEMP.	ENTHALPY
1	.000	.000		.000	41	522.548	485.854	480.	1619.536
2	.000	.000		.000	42	518.954	514.400		1722.680
3	.000	.000		.000	43	518.501	514.400		1722.672
4	.000	.000		.000	44	518.501	514.400		1722.672
5	853.200	531.000	531.	109.127	45	518.447	514.400	499.	1722.665
6	839.797	744.682		159.828	46	517.472	514.400		1722.656

TABLE 15 (Continued)

7	569.754	744.682	694.	.000	47	516.220	1168.578	1218.	4006.540
8	.000	744.682		.000	48	518.045	514.400		1722.665
9	.000	.000		.000	49	516.212	514.400		.000
10	569.754	744.682		.000	50	516.220	1133.836		3865.759
11	328.445	744.682		161.769	51	515.248	1133.836	1135.	3865.736
12	200.000	573.000	573.	.000	52	514.985	1133.836		3885.730
13	197.008	520.113	534.	.000	53	513.059	.000		.000
14	197.008	520.113		.000	54	513.059	757.879		2577.553
15	197.008	520.113		.000	55	514.290	1133.836		3885.713
16	200.000	665.000		.000	56	513.059	151.599	405.	1113.467
17	200.000	665.000		.000	57	512.400	757.879	737.	2577.539
18	200.000	665.000	BAD	.000	58	507.604	748.000	748.	2542.828
19	197.601	592.710	672.	.000	59	506.949	748.000		2542.815
20	.000	.000		.000	60	326.437	748.000		2539.028
21	.000	.000		.000	61	299.770	1960.000		4812.477
22	.000	.000		.000	62	299.693	1960.000	1960.	.000
23	.000	.000		.000	63	54.097	1645.071		.000
24	.000	.000		.000	64	15.611	1387.737		.000
25	.000	.000		.000	65	15.321	1387.737	1429.	3265.700
26	540.900	53.000		-52.538	66	14.051	787.894	840.	1981.020
27	540.568	53.000	53.	-52.544	67	13.473	787.894		.000
28	538.009	394.507		1279.823	68	.000	.000		.000
29	537.672	394.507		1279.820	69	.000	.000		.000
30	537.672	394.507		1279.820	70	.000	665.000		.000
31	537.338	394.507	407.	1279.818	71	.000	660.969		.000
32	531.883	467.000		1550.862	72	.000	680.648		.000
33	531.480	467.000		1550.857	73	.000	.000		.000
34	531.480	467.000		1550.857	74	.000	.000		.000
35	531.077	467.000	467.	1550.851	75	.000	.000		.000
36	527.477	561.747		1890.725	76	.000	.000		.000
37	526.995	561.747		1890.717	77	.000	.000		.000
38	526.995	561.747		1890.717	78	.000	.000		.000
39	526.516	561.747	540.	1890.708	79	13.968	.092		.000
40	522.974	485.854		1619.542	80	13.390	.095		1.000

TABLE 16

SIMULATION OF RUN 170 EVENT 585

GARRETT * AIRESEARCH MANUFACTURING DIVISON LOS ANGELES, CALIF.

* CONDITION * BYPASS AMBIENT PRESSURE 13.39 PSIA. 06 MAR 75 11102143

HYDRAULIC POWER	163.00	GEAR BOX LOSS	24.00	FIRST STAGE POWER	131.52	SFC	2.386	APR	3.39
HYDRAULIC PUMP	39.31	LUBE PUMP	4.00	SECOND STAGE	98.80	O/F	.683		
TOTAL GEAR BOX	202.31			TOTAL TURBINE	230.31	PT OUT	13.439		

TURBINE INFORMATION

FLOW	8.045	PRESSURE	221.68	14.75	EFFICIENCY 1ST	.441	A1	.1517	A3	.6300
SPECIFIC HEAT RATIO	1.357	TEMPERATURE	1960.0	1414.3	EFFICIENCY 2ND	.524	A2	.2335	A4	.6935
PRESSURE RATIO	15.05	ENTHALPY	.0	.0	EFFICIENCT TOTAL	.546	NDOT	0.	N	63000.

CONTROL VALVES

	PREHEATER BYPASS	RECUPERATOR BYPASS	O2 PRES REG	OXYGEN FLOW	HYDROGEN FLOW
TEMPERATURE	1139.70	524.93	746.66	746.66	748.00
PRESSURE IN	544.59	546.11	861.99	570.80	540.64
PRESSURE OUT	543.65	545.25	570.80	243.02	241.30
EFFECTIVE AREA	.22332	.03841	.00322	.00466	.02894
FLOW	2.594	.632	3.266	3.266	4.780

HX NO.	FLOW	IN PRESSURE	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.	TEST HEAT TRANS.
1 COLD SIDE	4.780	558.23	556.84	46.00	397.14	-72.3	1290.0	.321	6511.66 BTU/MIN	5854.
HOT SIDE	2.186	544.22	543.65	1139.70	304.76	3906.8	927.4	.763	6 PASS COUNT	7602.
HX NO.	**FLOW**	**IN PRESSURE**	**OUT**	**IN TEMP**	**OUT**	**IN H**	**OUT**	**EFF.**	**HEAT TRANS.**	
3 COLD SIDE	4.780	556.48	553.51	397.14	466.00	1290.0	1547.5	.445	1230.68 BTU/MIN	1936.
HOT SIDE	4.760	550.64	548.76	551.89	480.12	1856.6	1599.1	.464	6 PASS PARALL	1366.
HX NO.	**FLOW**	**IN PRESSURE**	**OUT**	**IN TEMP**	**OUT**	**IN H**	**OUT**	**EFF.**	**HEAT TRANS.**	
5 COLD SIDE	4.780	553.09	551.14	466.00	551.89	1547.5	1856.6	.540	1477.60 BTU/MIN	1582.
HOT SIDE	57.000	200.00	197.39	625.00	575.03	.0	.0	.314	4 PASS COUNT	BAD
HX NO.	**FLOW**	**IN PRESSURE**	**OUT**	**IN TEMP**	**OUT**	**IN H**	**OUT**	**EFF.**	**HEAT TRANS.**	
6 COLD SIDE	4.780	548.54	546.59	480.12	524.93	1599.1	1761.0	.408	773.88 BTU/MIN	532.
HOT SIDE	28.500	200.00	197.89	590.00	529.22	.0	.0	.553	4 PASS COUNT	358.
HX NO.	**FLOW**	**IN PRESSURE**	**OUT**	**IN TEMP**	**OUT**	**IN H**	**OUT**	**EFF.**	**HEAT TRANS.**	
8 COLD SIDE	4.148	545.83	545.25	524.93	1232.27	1761.0	4230.2	.795	10243.35 BTU/MIN	11922.
HOT SIDE	8.045	14.56	13.77	1414.30	820.18	3323.2	2046.1	.668	2 PASS COUNT	11401.
HX NO.	**FLOW**	**IN PRESSURE**	**OUT**	**IN TEMP**	**OUT**	**IN H**	**OUT**	**EFF.**	**HEAT TRANS.**	
9 COLD SIDE	4.780	543.31	540.97	757.93	748.00	2578.4	2543.5	.044	-166.58 BTU/MIN	--
HOT SIDE	3.266	869.40	861.99	532.00	746.66	109.3	160.2	.950	1 PASS PARALL	-145.

EXHAUST DUCT	PT	PS	MACH
INLET	13.774	13.726	.071
EXIT	13.439	13.390	.073

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STATION	PRESSURE	TEMPERATURE	TEST TEMP.	ENTHALPY	STATION	PRESSURE	TEMPERATURE	TEST TEMP.	ENTHALPY
1	.000	.000		.000	41	548.535	480.118	478.	1599.063
2	.000	.000		.000	42	546.592	524.934		1760.965
3	.000	.000		.000	43	546.351	524.934		1760.961
4	.000	.000		.000	44	546.351	524.934		1760.961
5	869.400	532.000	532.	109.253	45	546.110	524.934	506.	1760.957
6	861.989	746.662		160.217	46	545.826	524.934		1760.953

TABLE 16 (Continued)

7	570.796	746.662	703.	.000	47	545.248	1232.266	1273.	4230.188
8	.000	746.662		.000	48	546.106	524.934		1760.957
9	.000	.000		.000	49	545.246	524.934		.000
10	570.796	746.662		.000	50	545.245	1139.699		3906.834
11	243.024	746.662		162.521	51	544.738	1139.699	1134.	3906.821
12	200.000	590.000	590.	.000	52	544.588	1139.699		3906.818
13	197.888	529.224	529.	.000	53	543.655	.000		.000
14	197.888	529.224		.000	54	543.654	757.932		2578.393
15	197.888	529.224		.000	55	544.224	1139.699		3906.809
16	200.000	625.000		.000	56	543.654	304.757	334.	927.372
17	200.000	625.000		.000	57	543.314	757.932	730.	2578.386
18	200.000	625.000	BAD	.000	58	540.973	748.000	748.	2543.536
19	197.389	575.029	574.	.000	59	540.636	748.000		2543.529
20	.000	.000		.000	60	241.383	748.000		2537.215
21	.000	.000		.000	61	221.741	1960.000		6810.600
22	.000	.000		.000	62	221.684	1960.000	1961.	.000
23	.000	.000		.000	63	40.462	1648.392		.000
24	.000	.000		.000	64	14.729	1414.305		.000
25	.000	.000		.000	65	14.558	1414.305	1449.	3323.171
26	558.400	46.000		-72.274	66	13.774	820.181	863.	2046.120
27	558.231	46.000	46.	-72.278	67	13.439	820.181		.000
28	556.842	397.142		1290.022	68	.000	.000		.000
29	556.663	397.142		1290.020	69	.000	.000		.000
30	556.663	397.142		1290.020	70	.000	625.000		.000
31	556.483	397.142	360.	1290.019	71	.000	620.789		.000
32	553.510	466.000		1547.489	72	.000	633.892		.000
33	553.298	466.000		1547.487	73	.000	.000		.000
34	553.298	466.000		1547.487	74	.000	.000		.000
35	553.087	466.000	466.	1547.484	75	.000	.000		.000
36	551.141	551.895		1856.611	76	.000	.000		.000
37	550.892	551.895		1856.607	77	.000	.000		.000
38	550.892	551.895		1856.607	78	.000	.000		.000
39	550.642	551.895	552.	1856.602	79	13.726	.071		.000
40	548.755	480.118		1599.066	80	13.390	.073		1.000

TABLE 17

SIMULATION OF RUN 170 EVENT 593

GARRETT * AIRESEARCH MANUFACTURING DIVISON LOS ANGELES, CALIF.

* CONDITION * BYPASS AMBIENT PRESSURE 13.39 PSIA. 04 MAR 75 11102123

HYDRAULIC POWER	60.00	GEAR BOX LOSS	24.00	FIRST STAGE POWER	77.95	SFC	3.117	AR=	3.39
HYDRAULIC PUMP	33.43	LUBE PUMP	4.00	SECOND STAGE	43.48	O/F	.684		
TOTAL GEAR BOX	93.43			TOTAL TURBINE	121.43	PT OUT	13.414		

TURBINE INFORMATION

FLOW	4.853	PRESSURE	133.70	13.98	EFFICIENCY 1ST	.437	A1	.1517	A3	.0300
SPECIFIC HEAT RATIO	1.357	TEMPERATURE	1960.0	1482.9	EFFICIENCY 2ND	.577	A2	.2335	A4	.0930
PRESSURE RATIO	9.57	ENTHALPY	.0	.0	EFFICIENCY TOTAL	.544	NOCT	0.	N	63000.

CONTROL VALVES

	PREHEATER BYPASS	RECUPERATOR BYPASS	O2 PRES REG	OXYGEN FLOW	HYDROGEN FLOW
TEMPERATURE	1107.40	541.71	746.79	746.79	747.00
PRESSURE IN	563.70	564.16	879.06	571.87	562.37
PRESSURE OUT	563.43	563.94	571.87	146.59	145.52
EFFECTIVE AREA	.27224	.11261	.00189	.00281	.01677
FLOW	1.749	.927	1.971	1.971	2.882

HX NO.	FLOW	IN PRESSURE	OUT PRESSURE	IN TEMP	OUT TEMP	IN H	OUT H	EFF.	HEAT TRANS.	TEST HEAT TRANS.
1 COLD SIDE	2.882	568.64	568.14	50.00	374.85	-61.1	1204.5	.367	3647.78 BTU/MIN	3592.
HOT SIDE	1.133	563.57	563.43	1107.40	215.68	3795.0	575.1	.843	6 PASS COUNT	4244.
3 COLD SIDE	2.882	568.02	566.93	374.85	466.00	1204.5	1547.7	.458	989.21 BTU/MIN	1090.
HOT SIDE	2.882	565.87	565.15	573.96	477.84	1934.2	1591.0	.483	6 PASS PARALL	1104.
5 COLD SIDE	2.882	566.78	566.05	466.00	573.96	1547.7	1934.2	.701	1114.08 BTU/MIN	1212.
HOT SIDE	57.000	200.00	197.43	620.00	582.37	.0	.0	.244	4 PASS COUNT	BAD
6 COLD SIDE	2.882	565.07	564.34	477.84	541.71	1591.0	1821.2	.569	663.49 BTU/MIN	541.
HOT SIDE	28.500	200.00	198.07	590.00	538.08	.0	.0	.463	4 PASS COUNT	257.
8 COLD SIDE	1.955	564.08	563.94	541.71	1375.72	1821.1	4736.2	.886	5698.83 BTU/MIN	6643.
HOT SIDE	4.853	13.91	13.56	1482.89	935.83	3470.6	2296.3	.581	2 PASS COUNT	6293.
9 COLD SIDE	2.882	563.32	562.48	756.91	747.00	2575.2	2540.5	.044	-100.10 BTU/MIN	--
HOT SIDE	1.971	882.00	879.06	533.00	746.79	109.4	160.2	.955	1 PASS PARALL	-91.

EXHAUST DUCT	PT	PS	MACH
INLET	13.555	13.535	.046
EXIT	13.414	13.390	.051

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STATION	PRESSURE	TEMPERATURE	TEST TEMP.	ENTHALPY	STATION	PRESSURE	TEMPERATURE	TEST TEMP.	ENTHALPY
1	.000	.000		.000	41	565.073	477.839	475.	1590.960
2	.000	.000		.000	42	564.343	541.712		1821.154
3	.000	.000		.000	43	564.256	541.712		1821.153
4	.000	.000		.000	44	564.256	541.712		1821.153
5	882.000	533.000	533.	109.406	45	564.168	541.712	523.	1821.151
6	879.059	746.792		160.186	46	564.077	541.712		1821.150

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TABLE 17 (Continued)

7	571.866	746.792	706.	.000	47	563.940	1375.719	1364.	4736.178
8	.000	746.792		.000	48	564.159	541.712		1821.151
9	.000	.000		.000	49	563.944	541.712		.000
10	571.866	746.792		.000	50	563.938	1107.396		3744.973
11	146.590	746.792		162.926	51	563.760	1107.396	1097.	3744.969
12	200.000	590.000	590.	.000	52	563.703	1107.396		3744.968
13	198.065	538.076	546.	.000	53	563.435	.000		.000
14	198.065	538.076		.000	54	563.435	756.906		2575.221
15	198.065	538.076		.000	55	563.567	1107.396		3790.965
16	200.000	620.000		.000	56	563.435	215.678	284.	575.063
17	200.000	620.000		.000	57	563.315	756.906	725.	2575.214
18	200.000	620.000	BAD	.000	58	562.485	747.000	747.	2540.488
19	197.427	582.367	579.	.000	59	562.367	747.000		2540.486
20	.000	.000		.000	60	145.517	747.000		2531.672
21	.000	.000		.000	61	133.732	1960.000		6808.485
22	.000	.000		.000	62	133.698	1960.000	1956.	.000
23	.000	.000		.000	63	24.830	1653.728		.000
24	.000	.000		.000	64	13.975	1482.892		.000
25	.000	.000		.000	65	13.906	1482.892	1486.	3470.574
26	568.700	50.000		-61.115	66	13.555	935.833	957.	2296.280
27	568.636	50.000	50.	-61.116	67	13.414	935.833		.000
28	568.137	374.854		1204.465	68	.000	.000		.000
29	568.076	374.854		1204.465	69	.000	.000		.000
30	568.076	374.854		1204.465	70	.000	620.000		.000
31	568.016	374.854	368.	1204.465	71	.000	612.473		.000
32	566.932	466.000		1547.666	72	.000	617.335		.000
33	566.857	466.000		1547.665	73	.000	.000		.000
34	566.857	466.000		1547.665	74	.000	.000		.000
35	566.782	466.000	466.	1547.664	75	.000	.000		.000
36	566.052	573.961		1934.190	76	.000	.000		.000
37	565.961	573.961		1934.188	77	.000	.000		.000
38	565.961	573.961		1934.188	78	.000	.000		.000
39	565.870	573.961	574.	1934.187	79	13.535	.046		.000
40	565.150	477.839		1590.962	80	13.590	.051		1.000

TABLE 18

SIMULATION OF RUN 170 EVENT 597

GARRETT * AIRESEARCH MANUFACTURING DIVISON LOS ANGELES, CALIF.

* CONDITION * BYPASS AMBIENT PRESSURE 13.39 PSIA. 04 MAR 75 11101158

HYDRAULIC POWER	27.00	GEAR BOX LOSS	24.00	FIRST STAGE POWER	61.14	SFC	3.441	AMB	3.39
HYDRAULIC PUMP	31.54	LUBE PUMP	4.00	SECOND STAGE	25.40	O/F	.684		
TOTAL GEAR BOX	58.54			TOTAL TURBINE	86.54	PT OUT	13.409		

TURBINE INFORMATION

FLOW	3.845	PRESSURE	105.93	13.80	EFFICIENCY 1ST	.335	A1	.1517	A3	.6300
SPECIFIC HEAT RATIO	1.357	TEMPERATURE	1960.0	1530.8	EFFICIENCY 2ND	.578	A2	.2335	A4	.6930
PRESSURE RATIO	7.68	ENTHALPY	.0	.0	EFFICIENCY TOTAL	.528	NOD1	0.	N	63000.

CONTROL VALVES

	PREHEATER BYPASS	RECUPERATOR BYPASS	O2 PRES REG	OXYGEN FLOW	HYDROGEN FLOW
TEMPERATURE	1091.18	556.35	746.93	746.93	747.00
PRESSURE IN	569.98	570.24	880.84	572.19	569.15
PRESSURE OUT	569.82	570.12	572.19	116.15	115.28
EFFECTIVE AREA	.29218	.14898	.00149	.00222	.01313
FLOW	1.448	.914	1.561	1.561	2.284

HX NO.	FLOW	IN PRESSURE	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.	TEST HEAT TRANS.
1 COLD SIDE	2.284	573.06	572.76	48.00	358.57	-66.5	1141.1	.298	2757.70 BTU/MIN	2502.
HOT SIDE	.835	569.89	569.82	1091.18	177.24	3738.7	437.7	.876	6 PASS COUNT	2989.
HX NO.	FLOW	IN PRESSURE	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.	
3 COLD SIDE	2.284	572.69	572.01	358.57	465.00	1141.1	1544.1	.462	920.41 BTU/MIN	1114.
HOT SIDE	2.284	571.33	570.88	588.92	475.83	1986.7	1583.7	.491	6 PASS PARALL	1010.
HX NO.	FLOW	IN PRESSURE	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.	
5 COLD SIDE	2.284	571.92	571.45	465.00	588.92	1544.1	1986.7	.775	1010.90 BTU/MIN	1087.
HOT SIDE	57.000	200.00	197.50	625.00	591.07	.0	.0	.212	4 PASS COUNT	BAD
HX NO.	FLOW	IN PRESSURE	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.	
6 COLD SIDE	2.284	570.85	570.36	475.83	556.35	1583.7	1872.6	.649	659.76 BTU/MIN	520.
HOT SIDE	28.500	200.00	198.33	600.00	548.77	.0	.0	.413	4 PASS COUNT	261.
HX NO.	FLOW	IN PRESSURE	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.	
8 COLD SIDE	1.370	570.20	570.12	556.35	1447.91	1872.6	4990.7	.915	4271.88 BTU/MIN	4739.
HOT SIDE	3.845	13.75	13.51	1530.85	1014.10	3574.1	2463.2	.530	2 PASS COUNT	4697.
HX NO.	FLOW	IN PRESSURE	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.	
9 COLD SIDE	2.284	569.75	569.22	756.86	747.00	2575.2	2540.6	.044	-78.97 BTU/MIN	--
HOT SIDE	1.561	882.80	880.84	534.00	746.93	109.6	160.2	.955	1 PASS PARALL	-71.

EXHAUST DUCT	PT	PS	MACH
INLET	13.506	13.492	.038
EXIT	13.409	13.390	.040

STATION	PRESSURE	TEMPERATURE	TEST TEMP.	ENTHALPY	STATION	PRESSURE	TEMPERATURE	TEST TEMP.	ENTHALPY
1	.000	.000		.000	41	570.831	475.827	474.	1583.676
2	.000	.000		.000	42	570.365	556.354		1872.566
3	.000	.000		.000	43	570.308	556.354		1872.565
4	.000	.000		.000	44	570.308	556.354		1872.565
5	882.800	534.000	534.	109.644	45	570.253	556.354	535.	1872.564
6	880.843	746.927		160.212	46	570.196	556.354		1872.563

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TABLE 18 (Continued)

7	572.185	746.927	706.	.000	47	570.122	1447.908	1392.	4990.725
8	.000	746.927		.000	48	570.244	556.354		1872.564
9	.000	.000		.000	49	570.122	556.354		.000
10	572.185	746.927		.000	50	570.123	1091.181		3738.745
11	116.152	746.927		165.051	51	570.016	1091.181	1067.	3738.742
12	200.000	600.000	600.	.000	52	569.976	1091.181		3738.741
13	198.328	548.770	558.	.000	53	569.820	.000		.000
14	198.328	548.770		.000	54	569.820	756.865		2575.213
15	198.328	548.770		.000	55	569.889	1091.181		3738.739
16	200.000	625.000		.000	56	569.820	177.243	284.	437.699
17	200.000	625.000		.000	57	569.746	756.865	725.	2575.211
18	200.000	625.000	BAD	.000	58	569.221	747.000	747.	2540.631
19	197.503	591.075	591.	.000	59	569.148	747.000		2540.629
20	.000	.000		.000	60	115.282	747.000		2531.026
21	.000	.000		.000	61	105.962	1960.000		6807.818
22	.000	.000		.000	62	105.935	1960.000	1954.	.000
23	.000	.000		.000	63	19.954	1656.600		.000
24	.000	.000		.000	64	13.795	1530.847		.000
25	.000	.000		.000	65	13.750	1530.847	1501.	3574.149
26	573.100	48.000		-86.460	66	13.506	1014.100	987.	2463.195
27	573.061	48.000	48.	-86.461	67	13.409	1014.100		.000
28	572.758	356.572		1141.052	68	.000	.000		.000
29	572.722	356.572		1141.052	69	.000	.000		.000
30	572.722	356.572		1141.052	70	.000	625.000		.000
31	572.686	356.572	335.	1141.052	71	.000	612.884		.000
32	572.011	465.000		1544.073	72	.000	615.070		.000
33	571.964	465.000		1544.073	73	.000	.000		.000
34	571.964	465.000		1544.073	74	.000	.000		.000
35	571.917	465.000	466.	1544.072	75	.000	.000		.000
36	571.449	588.922		1986.715	76	.000	.000		.000
37	571.391	588.922		1986.714	77	.000	.000		.000
38	571.391	588.922		1986.714	78	.000	.000		.000
39	571.333	588.922	592.	1986.713	79	13.492	.038		.000
40	570.879	475.827		1563.677	80	13.390	.046		1.000

TABLE 19

SIMULATION OF RUN 170 EVENT 573

GARRETT * AIRESEARCH MANUFACTURING DIVISON LOS ANGELES, CALIF.

* CONDITION * BYPASS AMBIENT PRESSURE 3.00 PSIA. 04 MAR 75 11:01:50

HYDRAULIC POWER	254.00	GEAR BOX LOSS	24.00	FIRST STAGE POWER	169.15	SFC	2.661	APH	3.59
HYDRAULIC PUMP	44.51	LUBE PUMP	4.00	SECOND STAGE	157.36	O/F	.682		
TOTAL GEAR BOX	298.51			TOTAL TURBINE	326.51	PT OUT	3.324		

TURBINE INFORMATION

FLOW	10.256	PRESSURE	282.68	8.14	EFFICIENCY 1ST	.443	A1	.1517	A3	.6300
SPECIFIC HEAT RATIO	1.357	TEMPERATURE	1960.0	1353.5	EFFICIENCY 2ND	.428	A2	.2335	A4	.6930
PRESSURE RATIO	34.71	ENTHALPY	.0	.0	EFFICIENCT TOTAL	.510	NDOT	-0.	N	63000.

CONTROL VALVES

	PREHEATER BYPASS	RECUPERATOR BYPASS	O2 PRES REG	OXYGEN FLOW	HYDROGEN FLOW
TEMPERATURE	1128.64	511.78	747.11	747.11	750.00
PRESSURE IN	520.51	523.24	844.73	559.63	513.54
PRESSURE OUT	518.89	523.12	559.63	309.84	307.99
EFFECTIVE AREA	.21797	.00100	.00418	.00604	.03930
FLOW	3.266	.006	4.159	4.159	6.097

HX NO.	FLOW	IN PRESSURE	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.	TEST HEAT TRANS.
1 COLD SIDE	6.097	543.21	540.97	52.00	387.64	-55.6	1253.6	.312	7981.73 BTU/MIN	8413.
HOT SIDE	2.832	519.90	518.89	1128.64	335.22	3867.8	1048.9	.737	6 PASS COUNT	9380.
HX NO.	FLOW	IN PRESSURE	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.	
3 COLD SIDE	6.097	540.38	535.56	387.64	468.00	1253.5	1554.6	.435	1835.35 BTU/MIN	1406.
HOT SIDE	6.097	530.79	527.61	572.54	488.02	1928.6	1627.5	.457	6 PASS PARALL	1352.
HX NO.	FLOW	IN PRESSURE	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.	
5 COLD SIDE	6.097	534.85	531.65	468.00	572.54	1554.6	1928.6	.505	2280.62 BTU/MIN	1643.
HOT SIDE	57.000	200.00	197.65	675.00	600.55	.0	.0	.360	4 PASS COUNT	BAD
HX NO.	FLOW	IN PRESSURE	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.	
6 COLD SIDE	6.097	527.23	524.04	488.02	511.78	1627.5	1713.4	.345	523.73 BTU/MIN	377.
HOT SIDE	28.500	200.00	196.01	557.00	515.10	.0	.0	.607	4 PASS COUNT	200.
HX NO.	FLOW	IN PRESSURE	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.	
8 COLD SIDE	6.091	522.71	521.51	511.78	1127.20	1713.3	3862.8	.731	13092.45 BTU/MIN	15240.
HOT SIDE	10.256	7.66	5.12	1353.46	757.51	3193.1	1916.4	.708	2 PASS COUNT	14657.
HX NO.	FLOW	IN PRESSURE	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.	
9 COLD SIDE	6.097	518.31	514.12	760.17	750.00	2585.7	2550.0	.044	-217.68 BTU/MIN	--
HOT SIDE	4.159	856.60	844.73	527.00	747.11	108.1	160.4	.944	1 PASS PARALL	-186.

EXHAUST DUCT	PT	PS	MACH
INLET	5.116	4.914	.242
EXIT	3.324	2.990	.394

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STATION	PRESSURE	TEMPERATURE	TEST TEMP.	ENTHALPY	STATION	PRESSURE	TEMPERATURE	TEST TEMP.	ENTHALPY
1	.000	.000		.000	41	527.228	488.016	480.	1627.458
2	.000	.000		.000	42	524.040	511.782		1713.355
3	.000	.000		.000	43	523.642	511.782		1713.349
4	.000	.000		.000	44	523.642	511.782		1713.349
5	856.600	527.000	527.	108.130	45	523.245	511.782	497.	1713.343
6	844.729	747.114		160.386	46	522.714	511.782		1713.335

TABLE 19 (Continued)

7	559.627	747.114	697.	.000	47	521.508	1127.199	1169.	3862.812
8	.000	747.114		.000	48	523.243	511.762		1713.343
9	.000	.000		.000	49	523.123	511.762		.000
10	559.627	747.114		.000	50	521.602	1128.641		3867.828
11	309.836	747.114		102.401	51	520.750	1128.641	1128.	3867.807
12	200.000	557.000	557.	.000	52	520.505	1128.641		3867.802
13	196.013	515.103	517.	.000	53	518.891	.000		.000
14	196.013	515.103		.000	54	518.891	760.167		2585.692
15	196.013	515.103		.000	55	519.897	1128.641		3867.787
16	200.000	675.000		.000	56	518.691	535.219	395.	1048.903
17	200.000	675.000		.000	57	518.309	760.167	738.	2585.680
18	200.000	675.000	BAD	.000	58	514.118	750.001	750.	2549.977
19	197.649	600.550	683.	.000	59	513.540	750.001		2549.965
20	.000	.000		.000	60	307.990	750.001		2545.635
21	.000	.000		.000	61	282.749	1960.000		6812.072
22	.000	.000		.000	62	282.676	1960.000	1962.	.000
23	.000	.000		.000	63	51.135	1645.765		.000
24	.000	.000		.000	64	8.144	1353.464		.000
25	.000	.000		.000	65	7.663	1353.464	1395.	3193.062
26	543.500	52.000		-55.549	66	5.116	757.512	802.	1916.448
27	543.208	52.000	52.	-55.554	67	3.324	858.954		.000
28	540.970	387.637		1253.551	68	.000	.000		.000
29	540.676	387.637		1253.549	69	.000	.000		.000
30	540.676	387.637		1253.549	70	.000	675.000		.000
31	540.383	387.637	409.	1253.547	71	.000	670.848		.000
32	535.564	468.000		1554.568	72	.000	690.394		.000
33	535.207	468.000		1554.563	73	.000	.000		.000
34	535.207	468.000		1554.563	74	.000	.000		.000
35	534.850	468.000	469.	1554.559	75	.000	.000		.000
36	531.655	572.540		1928.609	76	.000	.000		.000
37	531.223	572.540		1928.602	77	.000	.000		.000
38	531.223	572.540		1928.602	78	.000	.000		.000
39	530.792	572.540	539.	1928.594	79	4.914	.242		.000
40	527.605	486.016		1627.463	80	2.990	.394		1.000

TABLE 20

SIMULATION OF RUN 160 EVENT 543

GARRETT * AIRESEARCH MANUFACTURING DIVISON LOS ANGELES, CALIF.

* CONDITION * BYPASS AMBIENT PRESSURE 2.00 PSIA. 04 MAR 75 12149159

HYDRAULIC POWER	163.00	GEAR BOX LOSS	24.00	FIRST STAGE POWER	119.31	SFC	2.170	APH	3.39
HYDRAULIC PUMP	39.31	LUBE PUMP	4.00	SECOND STAGE	111.01	O/F	.681		
TOTAL GEAR BOX	202.31			TOTAL TURBINE	230.31	P1 OUT	2.284		

TURBINE INFORMATION

FLOW	7.318	PRESSURE	201.74	6.04	EFFICIENCY 1ST	.440	A1	.1517	A3	.6300
SPECIFIC HEAT RATIO	1.357	TEMPERATURE	1960.0	1360.6	EFFICIENCY 2ND	.428	A2	.2335	A4	.6930
PRESSURE RATIO	33.40	ENTHALPY	.0	.0	EFFICIENCY TOTAL	.507	NDOT	-0.	N	63000.

CONTROL VALVES

	PREHEATER BYPASS	RECUPERATOR BYPASS	O2 PRES REG	OXYGEN FLOW	HYDROGEN FLOW
TEMPERATURE	1056.75	523.53	749.91	749.91	751.01
PRESSURE IN	543.72	544.84	881.49	559.73	540.63
PRESSURE OUT	543.15	544.26	559.73	221.19	219.77
EFFECTIVE AREA	.29786	.07910	.00282	.00433	.02840
FLOW	2.807	1.066	2.966	2.966	4.352

HX NO.	FLOW	IN PRESSURE	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.	TEST HEAT TRANS.
1 COLD SIDE	4.352	554.85	553.89	50.00	323.91	-61.4	1003.9	.272	4636.67 BTU/MIN	4555.
HOT SIDE	1.545	543.41	543.15	1056.75	226.88	3618.4	618.1	.824	6 PASS COUNT	6748.
3 COLD SIDE	4.352	553.65	551.36	323.91	470.00	1003.9	1562.1	.440	2429.19 BTU/MIN	2502.
HOT SIDE	4.352	548.86	547.10	656.15	497.91	2221.9	1663.6	.476	6 PASS PARALL	1116.
5 COLD SIDE	4.352	851.00	849.33	470.00	656.15	1562.1	2221.9	.665	2871.48 BTU/MIN	1283.
HOT SIDE	97.000	200.00	197.97	780.00	661.80	.0	.0	.315	4 PASS COUNT	BAD
6 COLD SIDE	4.352	546.91	545.25	497.91	523.53	1663.6	1755.9	.441	401.47 BTU/MIN	342.
HOT SIDE	20.500	200.00	196.49	556.00	523.99	.0	.0	.551	4 PASS COUNT	207.
8 COLD SIDE	3.287	544.64	544.27	523.53	1229.65	1755.9	4220.9	.844	8101.56 BTU/MIN	10835.
HOT SIDE	7.318	5.71	3.75	1360.62	844.17	3209.3	2102.2	.617	2 PASS COUNT	10523.
9 COLD SIDE	4.352	542.87	540.91	762.00	751.01	2592.9	2554.1	.044	-169.00 BTU/MIN	--
HOT SIDE	2.966	887.50	881.49	811.00	749.91	104.0	160.9	.052	1 PASS PARALL	-144.

EXHAUST DUCT	PT	PS	MACH
INLET	3.753	3.597	.249
EXIT	2.284	2.000	.442

18

STATION	PRESSURE	TEMPERATURE	TEST TEMP.	ENTHALPY	STATION	PRESSURE	TEMPERATURE	TEST TEMP.	ENTHALPY
1	.000	.000		.000	41	546.913	497.913	480.	1663.644
2	.000	.000		.000	42	545.252	523.527		1755.889
3	.000	.000		.000	43	545.053	523.527		1755.885
4	.000	.000		.000	44	545.053	523.527		1755.885
5	887.500	511.000	511.	103.973	45	544.853	523.527	500.	1755.882
6	881.488	749.907		160.917	46	544.636	523.527		1755.879

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TABLE 20 (Continued)

7	559.727	749.907	696.	.000	47	544.271	1229.650	1175.	4220.945
8	.000	749.907		.000	48	544.841	523.527		1755.862
9	.000	.000		.000	49	544.265	523.527		.000
10	559.727	749.907		.000	50	544.260	1056.753		3618.438
11	221.190	749.907		163.322	51	543.683	1056.753	1129.	3618.429
12	200.000	556.000	556.	.000	52	543.723	1056.753		3618.425
13	196.494	523.990	512.	.000	53	543.153	.000		.000
14	196.494	523.990		.000	54	543.153	762.084		2592.929
15	196.494	523.990		.000	55	543.406	1056.753		3618.417
16	200.000	750.000		.000	56	543.153	226.879	317.	618.063
17	200.000	750.000		.000	57	542.868	762.084	734.	2592.923
18	200.000	750.000	BAD	.000	58	540.909	751.013	751.	2554.093
19	197.971	661.804	729.	.000	59	540.629	751.013		2554.087
20	.000	.000		.000	60	219.768	751.013		2547.288
21	.000	.000		.000	61	201.792	1960.000		6810.175
22	.000	.000		.000	62	201.740	1960.000	1962.	.000
23	.000	.000		.000	63	36.943	1649.505		.000
24	.000	.000		.000	64	6.040	1360.619		.000
25	.000	.000		.000	65	5.708	1360.619	1383.	3209.319
26	555.000	50.000		-61.412	66	3.753	844.172	785.	2102.207
27	554.855	50.000	50.	-61.415	67	2.284	1020.174		.000
28	553.892	323.905		1003.944	68	.000	.000		.000
29	553.770	323.905		1003.944	69	.000	.000		.000
30	553.770	323.905		1003.944	70	.000	750.000		.000
31	553.648	323.905	318.	1003.944	71	.000	742.568		.000
32	551.360	470.000		1562.095	72	.000	754.331		.000
33	551.182	470.000		1562.093	73	.000	.000		.000
34	551.182	470.000		1562.093	74	.000	.000		.000
35	551.005	470.000	470.	1562.090	75	.000	.000		.000
36	549.335	656.146		2221.865	76	.000	.000		.000
37	549.096	656.145		2221.859	77	.000	.000		.000
38	549.096	656.145		2221.859	78	.000	.000		.000
39	548.858	656.145	547.	2221.858	79	3.597	.249		.000
40	547.102	497.913		1663.647	80	2.000	.442		1.000

TABLE 21

SIMULATION OF RUN 154 EVENT 510

GARRETT * AIRESEARCH MANUFACTURING DIVISON LOS ANGELES, CALIF.

* CONDITION * BYPASS AMBIENT PRESSURE 1.20 PSIA. 04 MAR 75 12149140

HYDRAULIC POWER	60.00	GEAR BOX LOSS	24.00	FIRST STAGE POWER	62.85	SFC	2.531	ARH	3.39
HYDRAULIC PUMP	33.43	LUBE PUMP	4.00	SECOND STAGE	58.58	O/F	.684		
TOTAL GEAR BOX	93.43			TOTAL TURBINE	121.43	PI CUT	1.344		

TURBINE INFORMATION

FLOW	3.941	PRESSURE	108.56	3.43	EFFICIENCY 1ST	.435	A1	.1517	A3	.0300
SPECIFIC HEAT RATIO	1.357	TEMPERATURE	1960.0	1372.4	EFFICIENCY 2ND	.427	A2	.2335	A4	.0930
PRESSURE RATIO	31.66	ENTHALPY	.0	.0	EFFICIENCY TOTAL	.502	NDOT	=0.	N	63000.

CONTROL VALVES

	PREHEATER BYPASS	RECUPERATOR BYPASS	O2 PRES REG	OXYGEN FLOW	HYDROGEN FLOW
TEMPERATURE	1048.14	546.60	746.91	746.91	747.00
PRESSURE IN	565.64	565.94	881.39	559.98	564.79
PRESSURE OUT	565.49	565.80	559.98	119.03	118.14
EFFECTIVE AREA	.31960	.10925	.00152	.00233	.01356
FLOW	1.581	.739	1.600	1.600	2.340

HX NO.	FLOW	IN PRESSURE	OUT PRESSURE	IN TEMP	OUT TEMP	IN H	OUT H	EFF.	HEAT TRANS.	TEST HEAT TRANS.
1 COLD SIDE	2.340	568.86	568.57	49.00	318.94	-63.8	984.1	.270	2452.70 BTU/MIN	2565.
HOT SIDE	.760	565.55	565.49	1048.14	154.43	3589.0	360.9	.894	6 PASS COUNT	5672.
3 COLD SIDE	2.340	568.51	567.83	318.94	465.00	984.1	1544.0	.457	1310.42 BTU/MIN	1098.
HOT SIDE	2.340	567.11	566.61	638.46	480.39	2160.2	1600.3	.495	6 PASS PARALL	709.
5 COLD SIDE	2.340	567.73	567.24	465.00	638.46	1544.0	2160.2	.807	1442.19 BTU/MIN	769.
HOT SIDE	57.000	200.00	197.81	880.00	633.78	.0	.0	.215	4 PASS COUNT	BAD
6 COLD SIDE	2.340	566.56	566.06	480.39	546.60	1600.3	1838.3	.639	557.03 BTU/MIN	435.
HOT SIDE	28.500	200.00	198.02	984.00	540.35	.0	.0	.821	4 PASS COUNT	329.
8 COLD SIDE	1.602	565.89	565.80	546.60	1279.47	1838.3	4397.0	.887	4098.32 BTU/MIN	5387.
HOT SIDE	3.941	3.26	2.11	1372.44	886.94	3231.9	2191.9	.588	2 PASS COUNT	5266.
9 COLD SIDE	2.340	565.42	564.86	758.01	747.00	2579.1	2540.5	.044	-90.34 BTU/MIN	--
HOT SIDE	1.600	883.40	881.39	510.00	746.91	103.8	160.2	.955	1 PASS PARALL	-76.

EXHAUST DUCT	PT	PS	MACH
INLET	2.108	2.023	.244
EXIT	1.344	1.200	.407

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STATION	PRESSURE	TEMPERATURE	TEST TEMP.	ENTHALPY	STATION	PRESSURE	TEMPERATURE	TEST TEMP.	ENTHALPY
1	.000	.000		.000	41	566.556	480.389	472.	1600.301
2	.000	.000		.000	42	566.065	546.597		1838.300
3	.000	.000		.000	43	566.007	546.597		1838.299
4	.000	.000		.000	44	566.007	546.597		1838.299
5	883.400	510.000	510.	103.759	45	565.949	546.597	521.	1838.298
6	881.392	746.907		160.205	46	565.888	546.597		1838.297

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TABLE 21 (Continued)

7	559.975	746.907	694.	.000	47	565.797	1279.472	1198.	4397.039
8	.000	746.907		.000	48	565.943	546.597		1838.297
9	.000	.000		.000	49	565.797	546.597		.000
10	559.975	746.907		.000	50	565.797	1048.140		3568.999
11	119.035	746.907		103.036	51	565.691	1048.140	1118.	3568.997
12	200.000	584.000	584.	.000	52	565.645	1048.140		3568.996
13	198.025	540.346	524.	.000	53	565.493	.000		.000
14	198.025	540.346		.000	54	565.494	758.012		2579.140
15	198.025	540.346		.000	55	565.548	1048.140		3588.993
16	200.000	680.000		.000	56	565.494	154.432	284.	360.881
17	200.000	680.000		.000	57	565.415	758.012	727.	2579.158
18	200.000	680.000	BAD	.000	58	564.863	747.000	747.	2540.538
19	197.806	633.740	725.	.000	59	564.786	747.000		2540.537
20	.000	.000		.000	60	118.143	747.000		2531.087
21	.000	.000		.000	61	108.592	1960.000		6807.881
22	.000	.000		.000	62	108.564	1960.000	1958.	.000
23	.000	.000		.000	63	20.298	1655.868		.000
24	.000	.000		.000	64	3.429	1372.436		.000
25	.000	.000		.000	65	3.258	1372.436	1361.	3231.899
26	568.900	49.000		-63.835	66	2.108	886.942	790.	2191.892
27	568.858	49.000	49.	-63.835	67	1.344	905.280		.000
28	568.574	318.943		984.121	68	.000	.000		.000
29	568.540	318.943		984.121	69	.000	.000		.000
30	568.540	318.943		984.121	70	.000	680.000		.000
31	568.506	318.943	338.	984.121	71	.000	670.748		.000
32	567.829	465.000		1544.018	72	.000	675.356		.000
33	567.780	465.000		1544.017	73	.000	.000		.000
34	567.780	465.000		1544.017	74	.000	.000		.000
35	567.731	465.000	465.	1544.017	75	.000	.000		.000
36	567.237	638.455		2160.217	76	.000	.000		.000
37	567.172	638.455		2160.215	77	.000	.000		.000
38	567.172	638.455		2160.215	78	.000	.000		.000
39	567.107	638.455	553.	2160.214	79	2.023	.244		.000
40	566.608	480.389		1600.302	80	1.200	.407		1.000

TABLE 22

SIMULATION OF RUN 154 EVENT 501

GARRETT * AIRESEARCH MANUFACTURING DIVISON LOS ANGELES, CALIF.

* CONDITION * BYPASS AMBIENT PRESSURE 1.20 PSIA. 04 MAR 75 12149107

HYDRAULIC POWER	27.00	GEAR BOX LOSS	24.00	FIRST STAGE POWER	44.92	SFC	2.917	AMB	3.39
HYDRAULIC PUMP	31.54	LUBE PUMP	4.00	SECOND STAGE	41.63	O/F	.083		
TOTAL GEAR BOX	58.54			TOTAL TURBINE	86.54	PT OUT	1.275		

TURBINE INFORMATION

FLOW	2.846	PRESSURE	78.42	2.64	EFFICIENCY 1ST	.432	A1	.1517	A3	.6300
SPECIFIC HEAT RATIO	1.357	TEMPERATURE	1960.0	1380.4	EFFICIENCY 2ND	.430	A2	.2335	A4	.6930
PRESSURE RATIO	29.71	ENTHALPY	.0	.0	EFFICIENCY TOTAL	.501	NCCT	-0.	N	63000.

CONTROL VALVES

	PREHEATER BYPASS	RECUPERATOR BYPASS	O2 PRES REG	OXYGEN FLOW	HYDROGEN FLOW
TEMPERATURE	1049.03	546.17	747.98	747.98	748.00
PRESSURE IN	569.68	569.84	874.05	560.31	569.21
PRESSURE OUT	569.61	569.76	560.31	85.99	85.35
EFFECTIVE AREA	.32864	.11113	.00111	.00168	.00972
FLOW	1.156	.552	1.155	1.155	1.691

HX NO.	FLOW	IN PRESSURE	OUT	IN TEMP	OUT	IN H	OUT	EFF.	HEAT TRANS.	TEST HEAT TRANS.
1 COLD SIDE	1.691	571.38	571.22	51.00	319.75	-58.0	987.3	.269	1767.75 BTU/MIN	1917.
HOT SIDE	.535	569.63	569.61	1049.03	131.59	3592.2	285.4	.919	6 PASS COUNT	2375.
3 COLD SIDE	1.691	571.19	570.82	319.75	466.00	987.3	1547.7	.465	947.59 BTU/MIN	732.
HOT SIDE	1.691	570.44	570.19	634.53	476.50	2146.5	1586.1	.502	6 PASS PARALL	635.
5 COLD SIDE	1.691	570.77	570.51	466.00	634.53	1987.7	2146.5	.869	1012.58 BTU/MIN	674.
HOT SIDE	57.000	200.00	197.76	660.00	627.12	.0	.0	.169	4 PASS COUNT	BAD
6 COLD SIDE	1.691	570.16	569.90	476.50	546.17	1586.1	1836.9	.745	423.96 BTU/MIN	342.
HOT SIDE	28.500	200.00	197.57	570.00	536.55	.0	.0	.358	4 PASS COUNT	231.
8 COLD SIDE	1.139	569.81	569.76	546.17	1292.99	1836.9	4444.8	.895	2969.42 BTU/MIN	3754.
HOT SIDE	2.846	2.52	1.71	1380.39	893.61	3249.8	2206.5	.580	2 PASS COUNT	3722.
9 COLD SIDE	1.691	569.57	569.25	759.00	748.00	2582.7	2544.1	.044	-65.18 BTU/MIN	--
HOT SIDE	1.155	875.20	874.05	511.00	747.98	104.1	160.5	.956	1 PASS PARALL	-52.

EXHAUST DUCT	PT	PS	MACH
INLET	1.710	1.656	.217
EXIT	1.275	1.200	.298

STATION	PRESSURE	TEMPERATURE	TEST TEMP.	ENTHALPY	STATION	PRESSURE	TEMPERATURE	TEST TEMP.	ENTHALPY
1	.000	.000		.000	41	570.163	476.503	472.	1586.142
2	.000	.000		.000	42	569.902	546.166		1836.855
3	.000	.000		.000	43	569.873	546.166		1836.854
4	.000	.000		.000	44	569.873	546.166		1836.854
5	875.200	511.000	511.	104.070	45	569.843	546.166	526.	1836.854
6	874.046	747.983		160.487	46	569.812	546.166		1836.853

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TABLE 22 (Continued)

7	560.305	747.983	681.	.000	47	569.763	1292.986	1201.	4444.761
8	.000	747.983		.000	48	569.839	546.166		1836.854
9	.000	.000		.000	49	569.761	546.166		.000
10	560.305	747.983		.000	50	569.763	1049.030		3592.167
11	85.992	747.983		103.401	51	569.708	1049.030	1100.	3592.166
12	200.000	570.000	570.	.000	52	569.682	1049.030		3592.185
13	197.568	536.549	526.	.000	53	569.607	.000		.000
14	197.568	536.549		.000	54	569.607	756.997		2562.681
15	197.568	536.549		.000	55	569.629	1049.030		3592.184
16	200.000	660.000		.000	56	569.607	131.586	284.	265.376
17	200.000	660.000		.000	57	569.566	758.997	732.	2562.660
18	200.000	660.000	BAD	.000	58	569.251	748.000	748.	2544.136
19	197.758	627.124	707.	.000	59	569.211	748.000		2544.135
20	.000	.000		.000	60	85.353	748.000		2533.880
21	.000	.000		.000	61	78.444	1960.000		6807.159
22	.000	.000		.000	62	78.424	1960.000	1953.	.000
23	.000	.000		.000	63	14.810	1659.180		.000
24	.000	.000		.000	64	2.640	1380.389		.000
25	.000	.000		.000	65	2.524	1380.389	1347.	3249.830
26	571.400	51.000		-58.038	66	1.710	893.609	790.	2206.527
27	571.378	51.000	51.	-58.039	67	1.275	1035.985		.000
28	571.224	319.752		987.348	68	.000	.000		.000
29	571.206	319.752		987.348	69	.000	.000		.000
30	571.206	319.752		987.348	70	.000	660.000		.000
31	571.189	319.752	350.	987.348	71	.000	648.259		.000
32	570.824	466.000		1547.717	72	.000	650.375		.000
33	570.799	466.000		1547.717	73	.000	.000		.000
34	570.799	466.000		1547.717	74	.000	.000		.000
35	570.773	466.000	466.	1547.716	75	.000	.000		.000
36	570.511	634.529		2146.521	76	.000	.000		.000
37	570.478	634.529		2146.520	77	.000	.000		.000
38	570.478	634.529		2146.520	78	.000	.000		.000
39	570.444	634.529	573.	2146.520	79	1.656	.217		.000
40	570.189	476.503		1586.142	80	1.200	.298		1.000

CONCLUSIONS AND RECOMMENDATIONS

Based on the results from 10 hours of system tests including 145 hot starts, the following conclusions can be drawn:

(1) The hydrogen-oxygen APU design developed under this program would be capable of furnishing Shuttle hydraulic power and performing hydraulic system cooling in a satisfactory manner consistent with currently known Shuttle requirements. However, the power level would have to be scaled down. The computer simulator model will be useful in the construction of a scaled-down prototype APU.

(2) The overall performance was near the computer simulator model predictions. Specific propellant consumption was 2.25 lb/hp-hr at 95 percent power and 4 lb/hp-hr at 10 percent power with space-simulated turbine exhaust conditioning, and 5.2 lb/hp-hr at 10 percent power and ambient turbine exhaust conditions.

(3) System startup to full power can be accomplished in about 1 to 2 sec, and the controller can perform the entire start sequences automatically.

(4) The electronic controller maintained turbine speed within the 1 percent specified limit during steady-state operation.

(5) The electronic controller maintained turbine inlet temperature within 40 R during steady-state operation and within 80 R during power transients of 150 hp.

(6) The electronic controller through the preheater bypass valve maintained the hydrogen temperature into the lube and hydraulic coolers between 860 and 920 R as required to prevent congealing or freezing.

(7) The electronic controller through the recuperator bypass valves maintained the combustor inlet temperatures near the 750 R set point.

The following recommendations are made for future APU improvements:

(1) The honeycomb seals on the turbine should be redesigned to reduce seal leakage.

(2) The combustor case should be redesigned to be less subject to distortion, and the spark plugs should be redesigned to prevent spark plug cavity breathing and the resultant overheating.

(3) The oxygen pressure regulators should be replaced by electronically controlled pressure regulators to increase response time. This will permit elimination of the oxygen accumulator from the system.

APPENDIX A

SUBSYSTEM TESTS

Combustor Tests

A series of development tests were conducted to verify the APU-T combustor design. The main objective was to obtain efficient combustion of a fuel-rich hydrogen-oxygen gas mixture within a minimum L*. To verify combustor design performance and meet performance objectives, the development effort consisted of:

(1) Configuration development - injector ΔP, flow distribution, operational checkout

(2) Ignition development

(3) Gas stream temperature profile determination

(4) Chamber wall thermal mapping

(5) Performance mapping - steady-state limits, lightoff limits

The hydrogen-oxygen combustor used in the development was as shown in fig. 6. The combustor was fabricated entirely of Type-347 corrosion-resistant steel except for the copper liner assembly. This prototype unit was built in several pieces and bolted together to facilitate examination, modification, and assembly. The only hardware modification required during testing, however, was to reduce the spark plug gap from 0.035 in. to 0.015 in. to obtain a spark at the higher operational pressures (200 to 300 psia before ignition). After these component development tests, the prototype unit was reworked and welded together for use in APU-T system tests.

Pressure measurements were taken to determine injector pressure drops, lightoff limits and combustor chamber pressure. Thermocouples were installed on the combustor walls to determine if design requirements were exceeded. Thermocouples were also located in the combustion chamber to determine gas stream profiles. An addition, the copper liner and combustion chamber, were coated with a thermal paint as an indication of maximum temperatures reached during testing. Instrumentation was recorded primarily on an oscillograph tape.

The combustor met all design performance requirements. Combustor test results were reported in ref. 1; some of the key results are summarized below.

> <u>Lightoff limits</u>.--The combustor was ignited and performance-tested over a range that exceeded the specified operational envelope of the test plan. Originally, the combustor was fitted with a spark plug with 0.035-in. electrode gap. Using this plug, it was found that the combustor failed to ignite at unlit chamber pressures in excess of 240 psia. A review indicated that a gap of 0.035 in. was too great; therefore, a spark plug with a 0.015-in. gap was used

instead and successful ignition was achieved under all conditions attempted. A summary of these conditions is presented in fig. 70, which shows successful ignition at points completely surrounding the APU operational envelope. The typical design points plotted were taken from a compilation of system computer runs.

Characteristic velocity (C*).--The characteristic velocity as determined by the test data is shown in fig. 71. Characteristic velocity was determined by the equation:

$$C^* = \frac{PA_t g}{w}$$

$$A_t = A_g f_{TR}$$

where A_g = geometric area of throat, sq. in.

f_{TR} = influence factor correcting for change in throat area caused by metal temperature change during firing

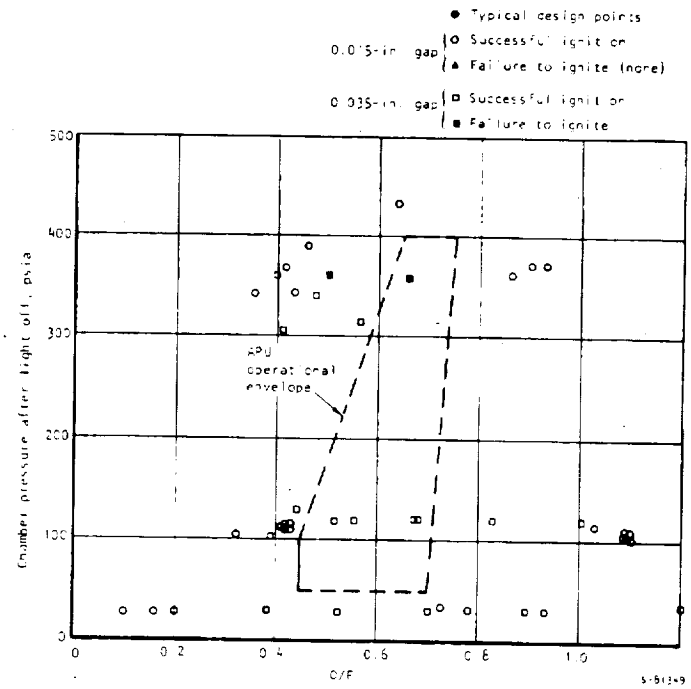
This was plotted against a background curve of theoretical C* provided by NASA for propellant inlet temperature of 530 R.

Gas stream temperature profile.--The gas stream profile was mapped by means of four thermocouples located 4.25 in. downstream of the injectors as shown in fig. 72. During the test sequence, the injector head and copper liner were rotated through five circumferential positions to provide for 20 temperature data points under each test condition. The location of each of these data points with respect to the injectors is shown in fig. 73. These results showed that the combustor and cooling gases were well mixed by this point.

Combustor exhaust temperature.--Combustor exhaust temperature data were obtained as shown in fig. 74. The measured values compared favorably with theoretical exhaust temperature.

Heat Exchanger Tests

Prior to installation in the APU-T test system, the H_2-O_2 APU heat exchangers (See fig. 9) were sujected to standard production acceptance tests. Performance tests of only the temperature equalizer were conducted using water as the test fluid. Although the slightly tapered construction of the heating equalizer cylinder should have promoted intimate contact, the efficiency of the brazed buffer fin joints was unknown. For the other heat exchangers, the performance prediction was not in question.



17,000 volts, 50 sparks/sec, 5 millijoules/spark, 0.015-in gap
test data 3-13-73

Figure 70.--Summary of Test Points.

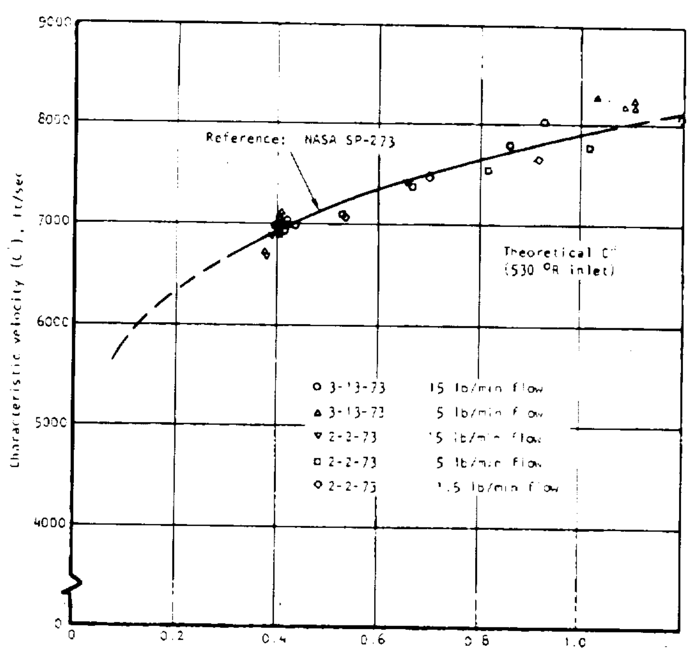


Figure 71.--Characteristic Velocity.

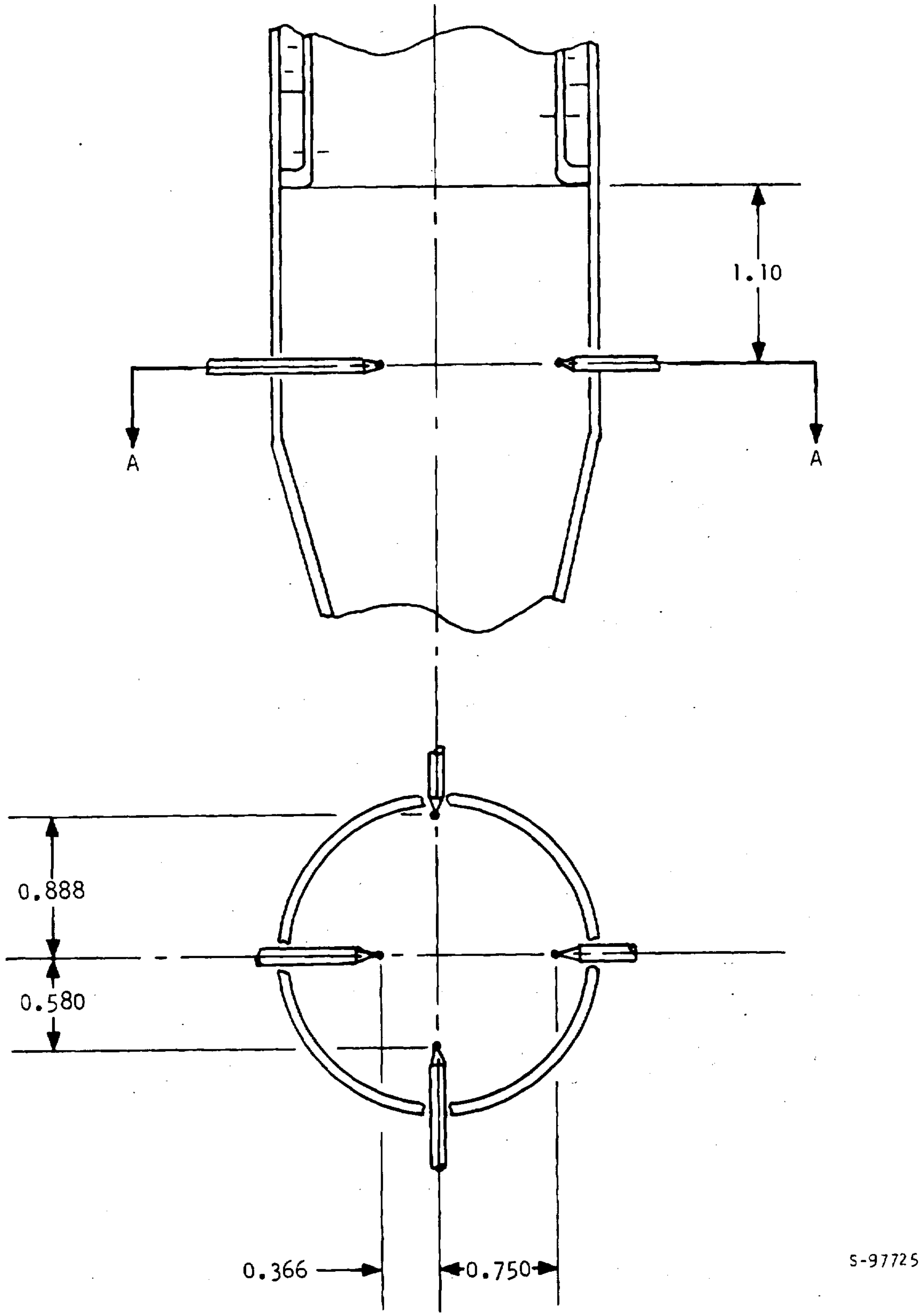
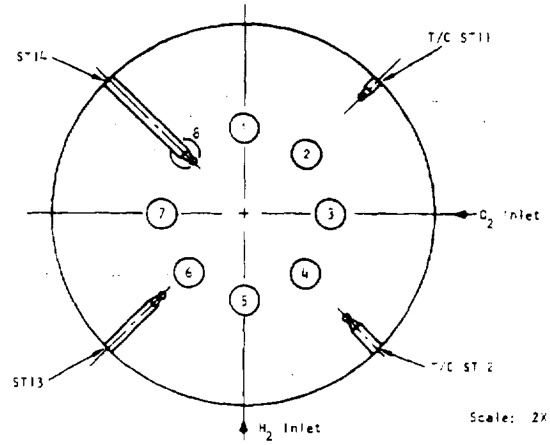
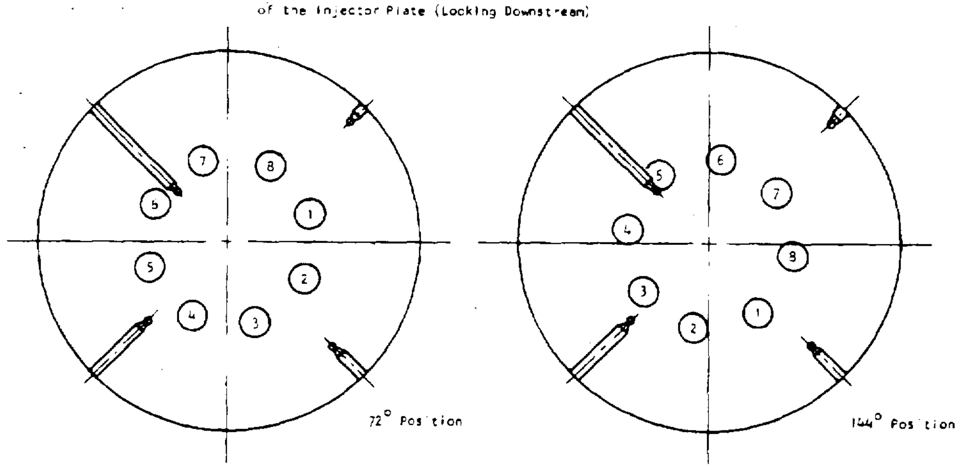


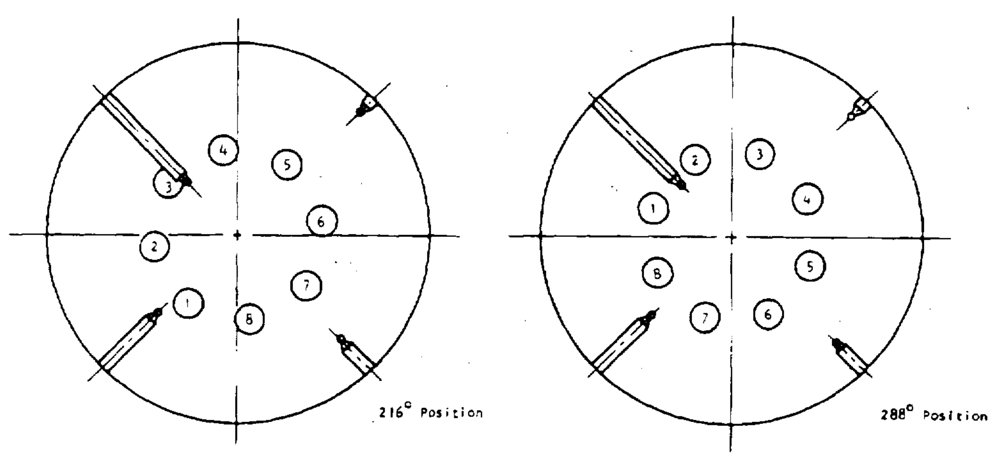
Figure 72.--Thermocouple Installation, Temperature Profile Test.



(a) Thermocouple Locations at 0° and 360° Rotational Positions of the Injector Plate (Looking Downstream)



(b) Relative Positions of Thermocouples and Injectors



(c) Relative Positions of Thermocouples and Injectors

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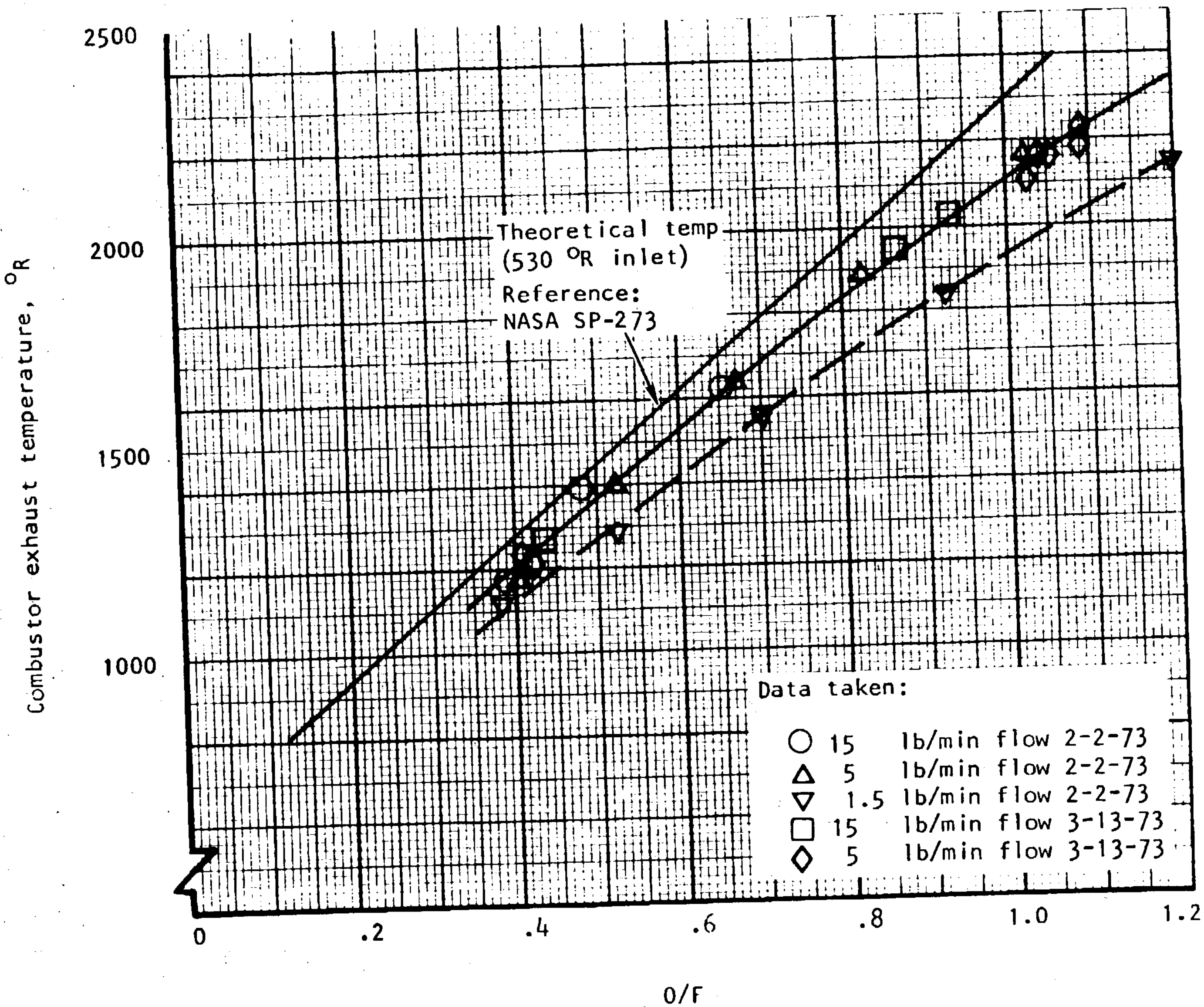
Figure 73.--Data Point Locations Relative to Injectors.



S-93921

Figure 74.--Combustion Temperature.

The tests conducted are summarized as follows:

Component	Pressure proof pressure	Helium mass spectrometer leakage	Isothermal pressure drop	Performance
Temperature equalizer	X	X		X
Preheater, regenerator	X	X	X	
Lube oil coolers	X	X	X	
Recuperator	X	X	X	

Performance test.--Performance of the temperature equalizer was as shown in fig. 75. The achieved performance was approximately 15 percent below predicted. This was illustrated in the ηhA curve. For the purpose of analysis and comparison, the entire buffer zone resistance was built into the oxygen side. It is believed that because of incomplete brazing, there was increased buffer zone resistance. The entire shift in the ηhA curve is attributed to the oxygen circuit.

Acceptance tests.--Analysis of acceptance test data indicated that the heat exchangers met requirements with the exception of the equalizer. Isothermal pressure drops were slightly below predictions for the hydraulic and lube oil coolers (a maximum of 15 percent in the hydrogen circuit for one unit) and closer to predicted for the preheater, regenerator, and recuperator. Neither difference was sufficient to significantly affect ηhA predictions.

Turbine-Gearbox Tests

The turbine-gearbox tests were conducted to assure that the unit was adequately lubricated, properly assembled, and capable of operation throughout the SSAPU speed range. The tests were scheduled to be conducted before the turbine was brazed into the APU-T system so that operational problems could be corrected without affecting the APU-T test schedule.

For the tests, the turbine-gearbox assembly was mounted on a 0 to 6000 rpm dynamometer test stand. The dynamometer drive was connnected to one of the pump drive pads with a splined quill shaft; the other pad was covered. Lubricant was supplied to the turbine-gearbox from the same facility equipment that was later used for the APU-T system tests. Three accelerometers were mounted on the unit to measure self-induced vibration. The test setup is shown in fig. 76.

For the lube oil flow verification, lube oil was flowed at 100 psi through each of the five inlet circuit ports, A, B, C, D, and E on fig. 76, to assure each had sufficient flow for lubrication. Orifices on the inlet were adjusted as required to obtain the desired flow distribution with results as shown in tables 23 and 24. Various orifices were used in circuit E (inlet to the

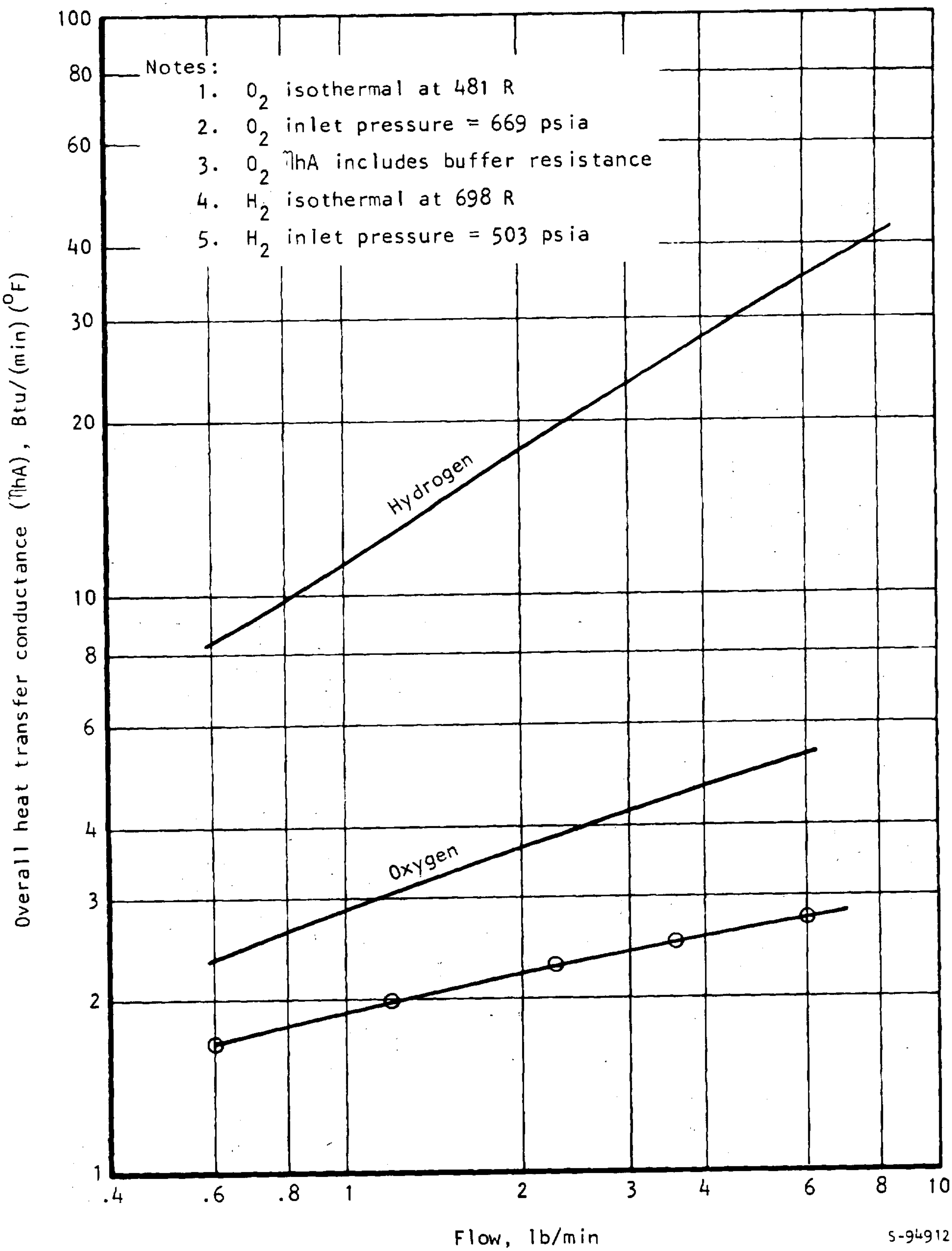


Figure 75.--Heat Transfer Conductance, SSAPU (Based on Test Data).

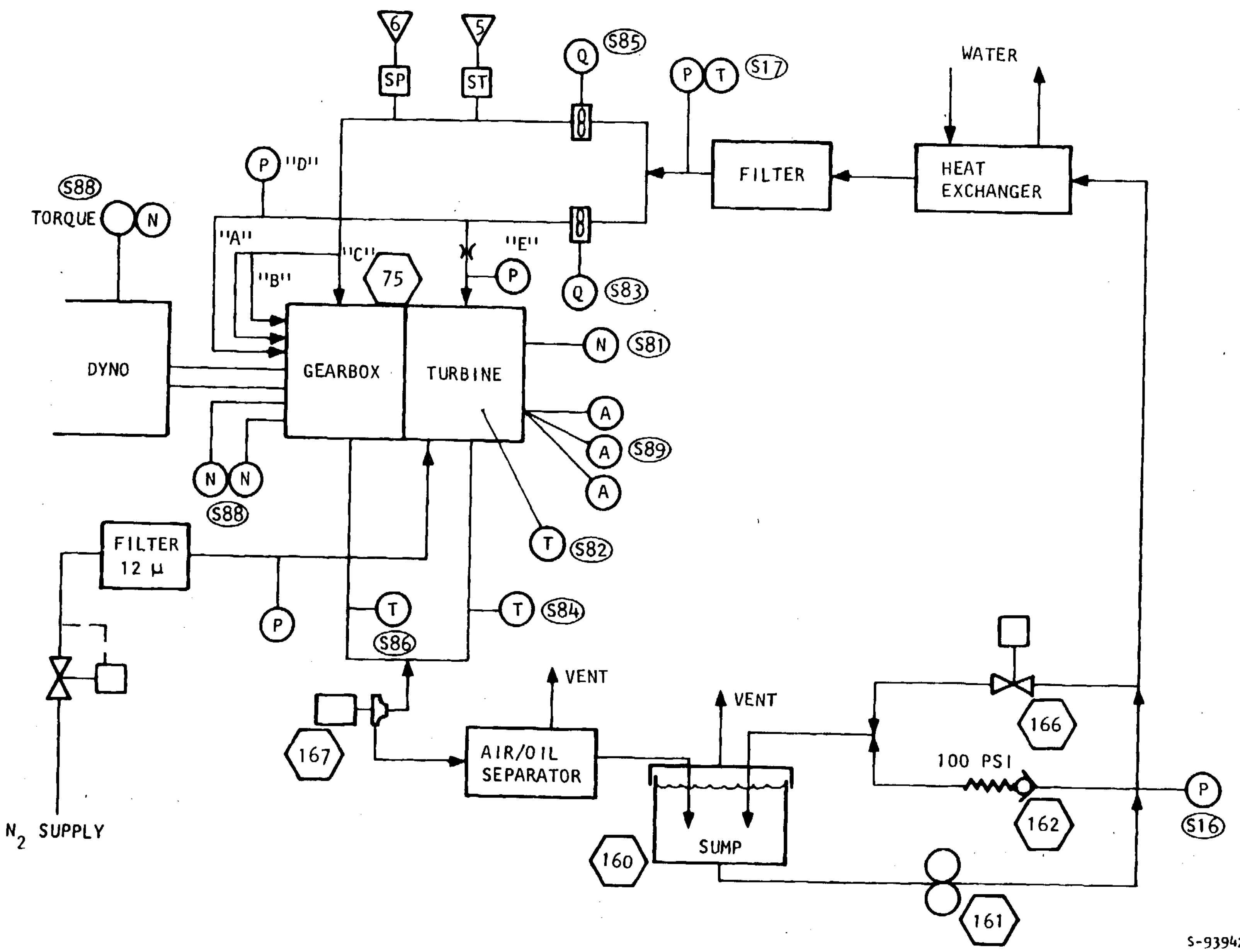


Figure 76.--Test Setup Schematic - Turbine/Gearbox Test.

TABLE 23

LUBE OIL FLOW

Circuit	Designation	Lubricated part	Flow rate, gpm	
			Predicted	Measured
A	PA-86964	Outboard pinion	0.16	0.13
B	Gearbox back	Pump drive gear	0.20	0.11
C	Gearbox front	Inboard pinion planet journals sun gear	1.07	0.46
D	Shaft	Turbine shaft (cooling)	2.22	2.23
E	Turbine	Turbine bearings	0.24	0.30
			3.89	3.23

TABLE 24

OPERATING CAPABILITY TEST SCHEDULE

Input speed, rpm*	Turbine speed, rpm	Dwell time, min
500	6274	23
1000	12 547	7
1500	18 821	13
2000	25 094	6
2500	31 368	5
3000	37 642	17
3500	43 915	5
4000	50 189	5
4500	56 462	7
5000	62 740	5
5253	65 915	4
		Total 79

*Measurements within ±3 rpm

turbine bearings) to determine the optimum (minimum bearing temperature change and maximum heat rejection) lube oil flow at nominal SSAPU operating speed. Results of these tests as shown in fig. 77 indicated that the optimum lube flow was 0.7 gpm. Therefore, the choke orifice at port E was removed.

For the subsequent operating capability tests, self-induced vibration and audible noise were observed during an excursion through the SSAPU turbine speed range; the nominal turbine speeds and the dwell times at each are tabulated in table 24. No excessive accelerations or audible noise was observed, and measured turbine bearing and lubricating oil temperatures and flow rates assured adequate turbine-gearbox lubrication for the subsequent APU-T system tests. A gearbox loss of 28 hp was calculated from the dynamometer tests (fig. 78).

Changes in the turbine-gearbox incident to the turbine-gearbox test program which were incorporated for the APU-T system tests are described below. Port designations correspond with those shown on fig. 76.

> Port A--Port A, originally a part of Port D, was added to separate turbine flow from gearbox flow for individual measurement.
>
> Port B--Port B, originally a single inlet dividing into separate jets to lubricate each pump drive gear, was made into two ports, each connecting to the gear through a separate removable bayonet with its own oil filter and jet, permitting individual measurement of lube oil flow to each gear and easy removal for cleaning if necessary.
>
> Port E--Port E, the turbine oil inlet, originally contained an 0.033-diameter orifice before dividing into the rear and front bearing flow passages. This orifice was removed to increase flow to the bearings.

Control Circuit Tests

Each circuit board was tested to verify that its functional characteristics were acceptable. The chassis mounts also were checked for proper functional characteristics. Typical procedures were as follows:

A1. The A1 board contains the thermocouple amplifiers for the turbine inlet temperature, plus overtemperature comparators. This card required a calibration to compensate for any initial errors. The circuit card was connected to a breakout box and the appropriate power sources were connected. An equivalent millivolt source was used to simulate the thermocouple signals. The test results are tabulated below.

Temperature	TIT (control)	TIT (overtemperature)
1000 R (2.500 V)	2.495 V	2.500 V
2000 R (5.000 V)	4.991 V	4.994 V

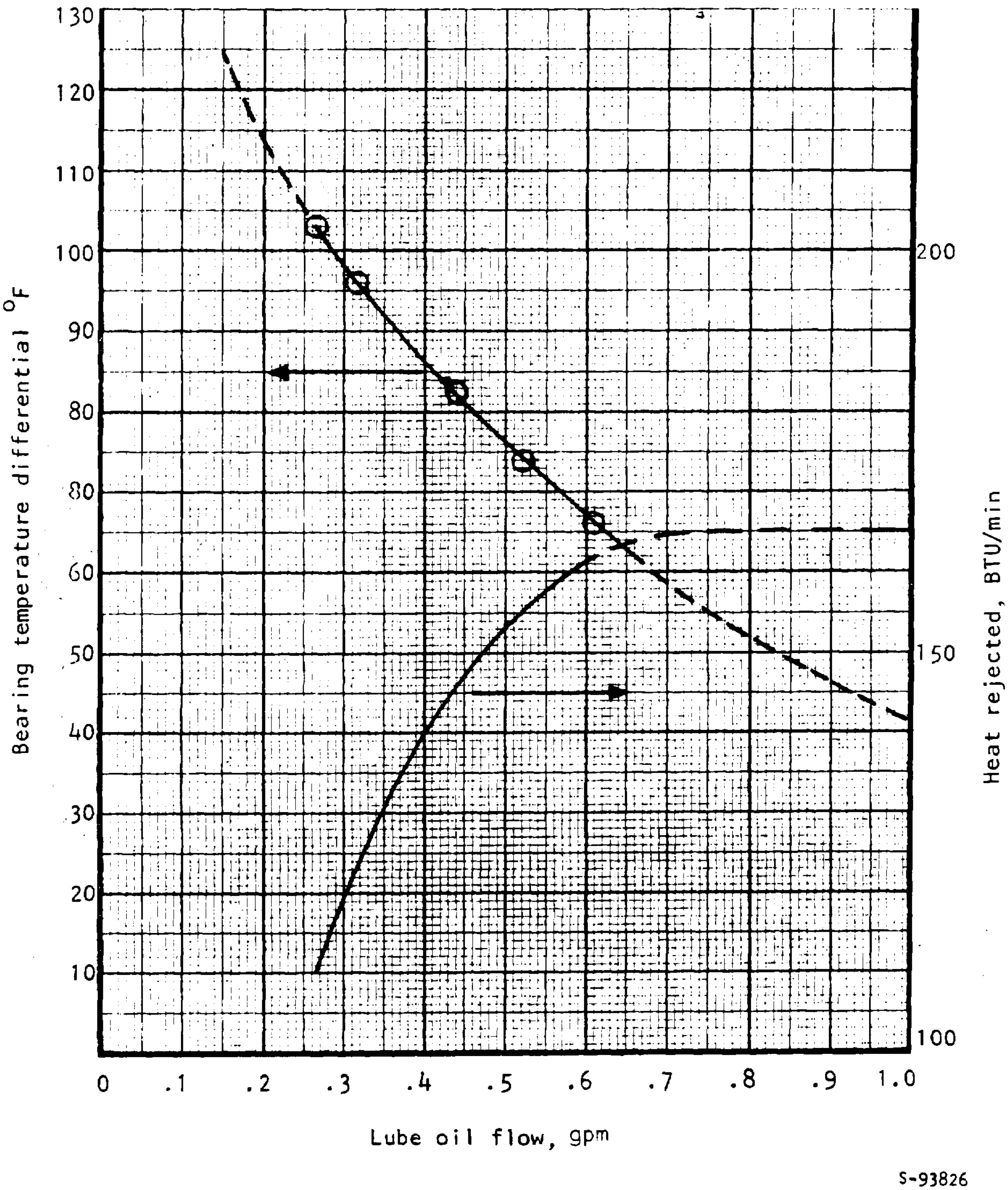


Figure 77.--Turbine Bearing Temperature at Various Lube Oil Flows.

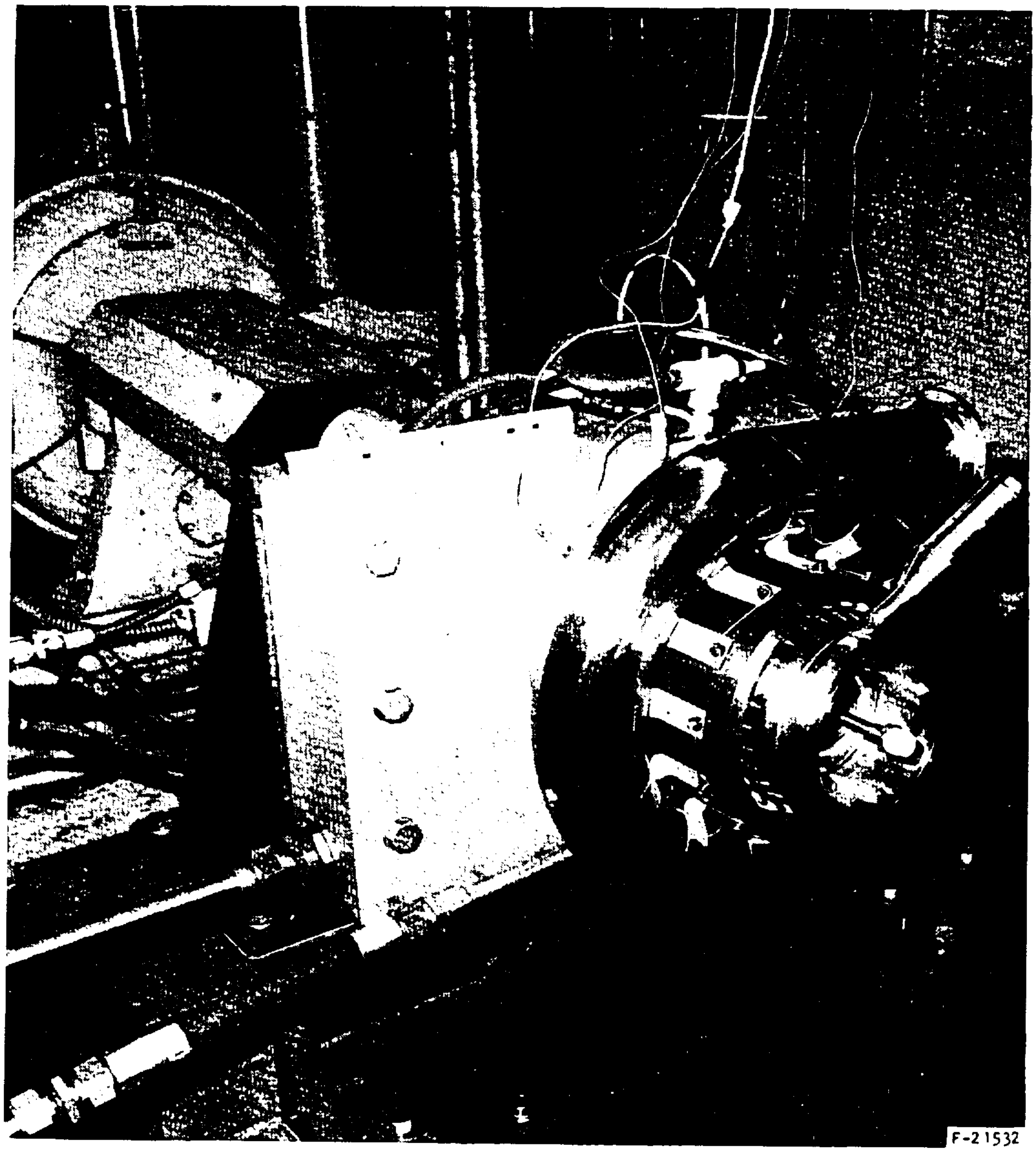


Figure 78.--Turbine/Gearbox Mechanical Drive Test Setup.

A2. The A2 card contains the thermocouple amplifiers for lube oil, T_{32}, and T_{58}. The test and calibration procedures were the same as those for A1. Results were:

Temperature	T_{32}
350 R	-0.406 V
400 R	0.055 V
460 R	0.659 V
500 R	1.086 V

Temperature	T_{58}
600 R	2.021
700 R	3.052
800 R	4.049
900 R	5.044

Temperature	Lube Oil
600 R	3.021
650 R	3.523
700 R	4.025
750 R	4.520

A3. The A3 card contains the turbine inlet temperature control loop. This card was tested similarly to the two previous circuit cards. Power sources were connected and adjusted to simulate condition signals with the following results:

TIT set point	Adjust pot setting
964 R	0.0000
1465 R	5.000
1959 R	10.000

A4. The A4 card contains the precision ±5 V ±0.1 percent power supplies used in the computation and control loops, and the modulating power source for all of the LVDT's and RVDT's for angular and positional feedback loops. These circuits were calibrated to within acceptable limits.

A5. The A5 card contains the turbine monopole signal conditions. Tabulated below are the test results.

$N_{control}$ (rpm)	V_{out}
10 000	0.797
20 000	1.593
40 000	3.182
63 000	5.008

$N_{overspeed}$ (rpm)	V_{out}
10 000	0.796
20 000	1.591
40 000	3.181
63 000	5.005
68 000	5.396

A6, A7. The A6 and A7 cards contain the position control for the bypass valves. The boards were tested and performed to expected limits.

A8, A9. The A8 and A9 cards contain the position control for the H_2 and O_2 flow control valves. The boards also contain the combustor pressure transducer signal conditioner. To calibrate the transducer, the actual device to be used was connected to the circuit card and calibrated.

A10. The A10 card is used to provide signal conditioning for the RVDT's and LVDT's. The final board calibration was performed at the test facility to obtain the proper match between signal conditioner and transducer.

A11 - A16. These cards contain circuits that did not require calibration, but each was tested to verify its performance. The cards provided for start-stop logic, hydrogen and oxygen control loops, instrumentation interface, buffer amplifier, and failure monitor.

Chassis.--The chassis subassemblies provided solenoid drivers, spark detector and relay drivers, ±15-V regulated power supplies, and the power amplifiers necessary to drive the flow control and bypass valves. All of these subassemblies were tested prior to chassis installation.

Control Subsystem Tests

The control subsystem test series used a turbine analog in place of the turbine and a dummy turbine inlet torus to permit extensive testing and evaluation of the combustor and its control system. The turbine analog was a black box with turbine performance and inertia built into it. The control subsystem test setup is shown in fig. 79, which includes a closeup view of the instrumentation used. Combustor inlet pressure and temperature were input and hydraulic loads were simulated to check turbine response characteristics. The tests were run with the combustor, and turbine inlet (simulated by the dummy torus) pressure and temperature were sensed and fed into the turbine analog.

The test series had two principal objectives:

(1) Check out the control circuit and prove that it would control the turbine inlet temperature to acceptable levels for all operating conditions; if it would not, develop improvements that would assure control.

(2) Calibrate the turbine inlet thermocouples used for the control system.

The objectives of the test series were met; that is, turbine inlet temperatures were controlled to acceptable levels, and the thermocouples were calibrated. However, improvements in the hydrogen control valve were made after the torque motor had failed repeatedly to meet response requirements. Replacement of the torque motor with a samarium cobalt dc motor improved response and assured control system stability during demonstration tests.

Test setup.--The control subsystem test setup is shown in fig. 80. This setup reflects improvements in the control subsystem developed during the control subsystem tests, a principal test objective. These improvements are described later under Test Results.

There are seven forcing functions for the controller:

(1) H_2 inlet temperature

(2) Turbine load

(3) H_2 inlet pressure

(4) Turbine exhaust pressure

(5) O_2 inlet temperature

(6) O_2 inlet pressure

(7) Heat load

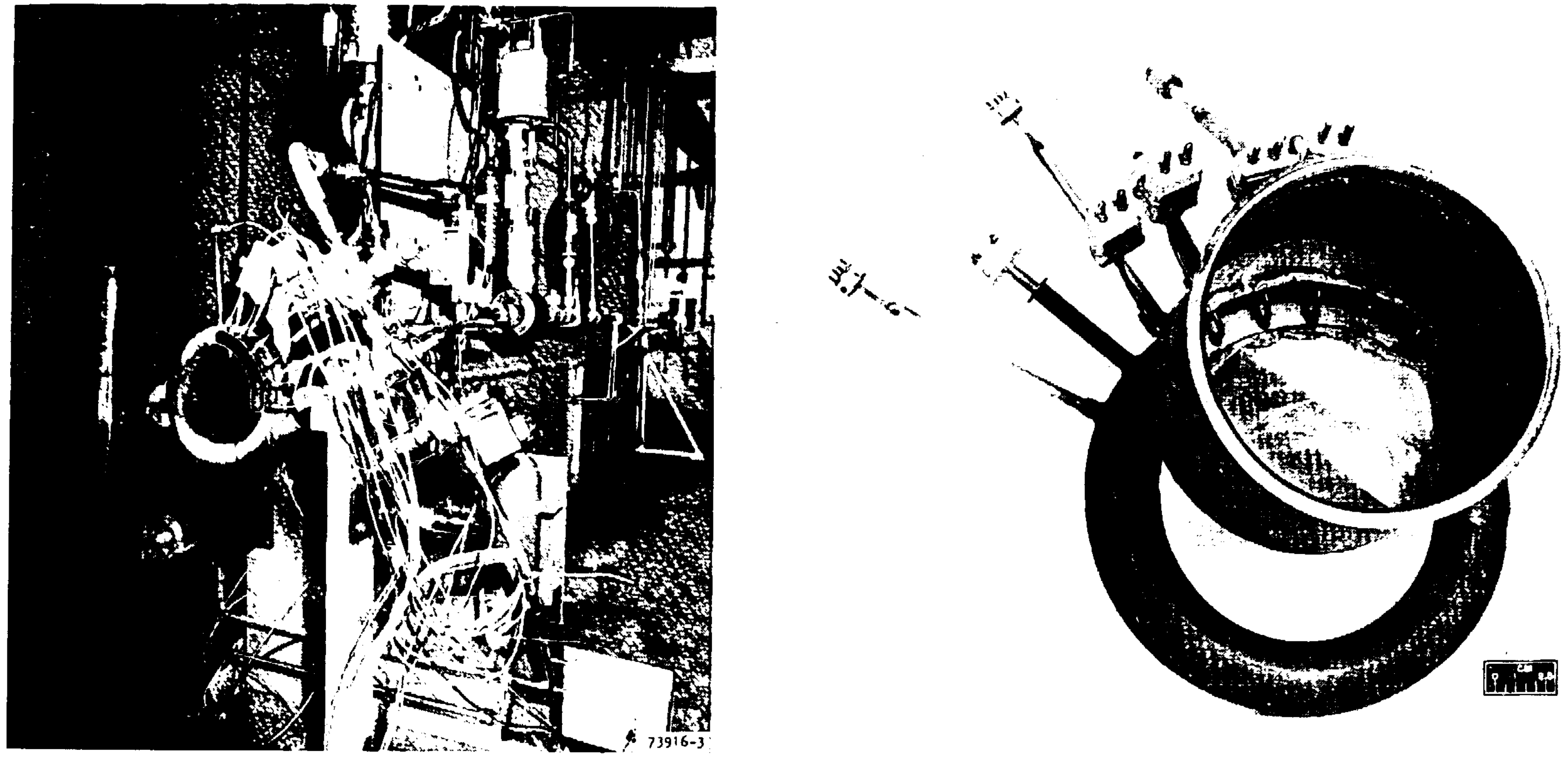


Figure 79.--Control Subsystem Test Setup and Instrumentation.

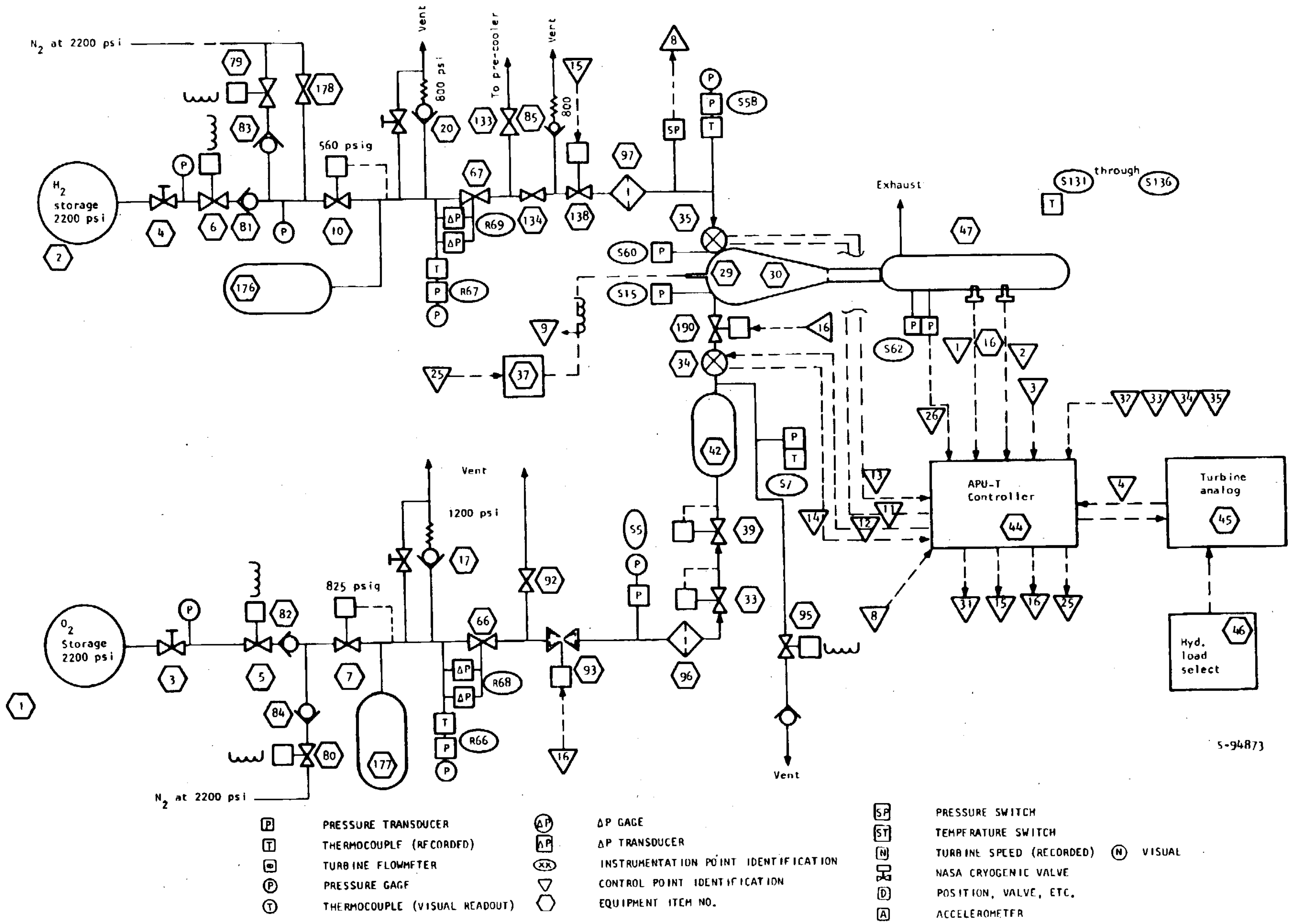


Figure 80.--Test Setup Schematic, Control Subsystem Test.

Only the turbine load was simulated in the turbine analog to check out the control subsystem.

The other forcing functions were eliminated for the following reasons:

(1) Hydrogen and oxygen inlet temperatures: Propellant inlet temperatures throughout this range were not expected to have significant effect upon the turbine inlet control circuits.

(2) Hydrogen and oxygen inlet pressures both have negligible effect on the system because they are regulated within a few psi. Interactions between the oxygen pressure regulators and the accumulator were included in the test system, and the results were closely examined for possible interactions.

(3) Turbine exhaust pressure: The effect of exhaust pressure changes was included in turbine load input.

(4) Heat load: Reflected only in H_2 inlet temperature.

The test matrix in table 25 was used to simulate steady-state loads from 0 to 400 hp and transient operating conditions.

Control subsystem testing and results.--Prior to the hot testing with the combustor, the torus nozzles were flow checked by flowing hydrogen through the setup. A total effective area of 0.15 sq. in. was obtained by adjusting the size of nozzle openings. The NASA V6 hydrogen venturi was used for the calibration.

The two control subsystem thermocouples were calibrated against the average temperature indicated by the six thermocouples inserted through the torus discharge nozzles. The flow around thermocouple ends was choked so no heat transfer would occur between the thermocouple bead and connecter. The true gas temperature in the torus was obtained using this method.

Initial tests were conducted to calibrate the flow control valve in the H_2 and O_2 circuits and to check out operation. Accumulators were added to the H_2-O_2 supply lines to attenuate pressure regulator response to changes in line pressure.

A second series of short duration operations at lower pressure and temperature to establish start capability revealed oxygen backflow and overheating of components located downstream of the oxygen shutoff valve. After experimentation with the oxygen check valve location, the check valve was eliminated and an additional oxygen shutoff valve (equipment identification 190, fig. 76) was added between the combustor and the control valve. Retention of oxygen at approximately 500 psig in the area between the two shutoff valves effectively prevented backflow. Additional control changes made to prevent inadvertent shutdown during start included increasing the TIT limit rate by a factor of 2, increasing the Delta TIT limit to 120 R, and increasing the delay time on control valve position versus commanded position from 20 to 40 msec.

TABLE 25

COMBUSTOR AND CONTROL SUBSYSTEM
CLOSED LOOP TEST MATRIX

	Turbine load hp (analog setting)	Test condition number
Steady state	0	1
	100	2
	200	3
	400	4
Cycling loads[a]	0-100	5
	0-200	6
	0-300	7
	0-400	8
	100-200	9
	100-300	10
	100-400	11
	200-300	12
	200-400	13
	300-400	14

[a] Load cycling was varied from 0.1 to 1.0 cps during each test.

Other improvements to the control subsystem include:

(1) Changed the filter time constant in the spark detection circuit to be compatible for a spark rate of 60 sparks/sec.

(2) Changed the feedback error detector circuit to eliminate nuisance shutdown.

(3) Developed a circuit to incorporate a 15-sec delay before the hydrogen shutoff valve was closed to permit hydrogen flow to cool down the combustor and the turbine area.

(4) Developed a circuit to lower combustor pressure setpoint in normal shutdown to 50 psig. It was found by later analysis that the original setpoint at 100 psig might overspeed the turbine with cold hydrogen operation.

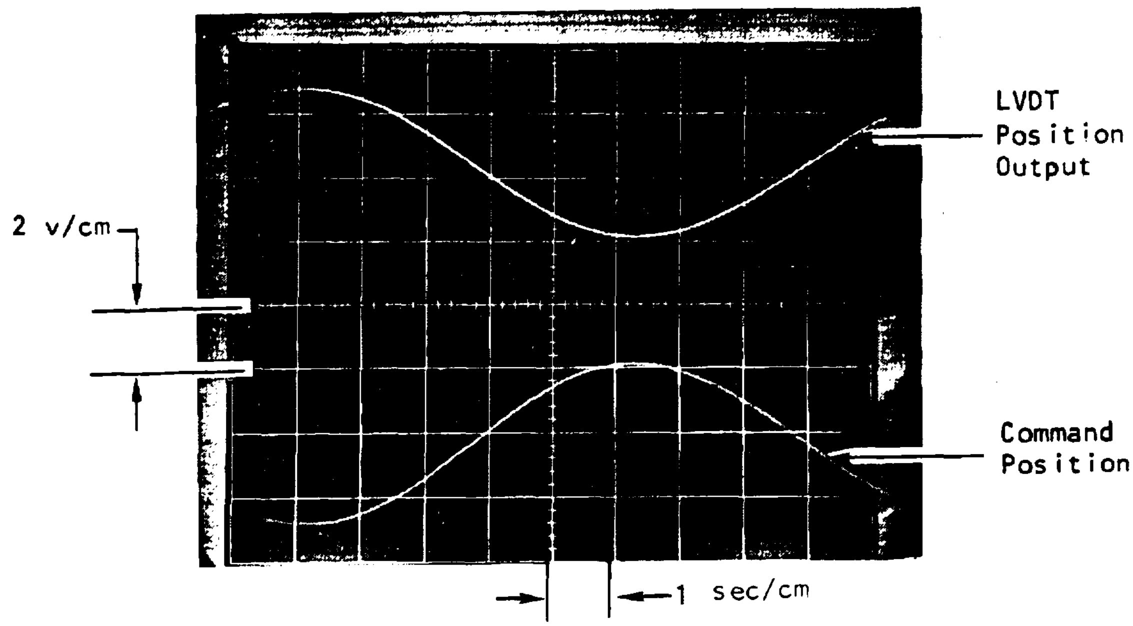
Valve development.--A 5-Hz oscillation of the O_2 control valve noted during steady-state operation was eliminated by reducing the temperature loop gain (by a factor of 4) to agree with control design. Subsequent operation duplicated the previous conditions (75 percent power, 1920 R, and 500 psig) with no O_2 control valve oscillation and no temperature overshoot or undershoot.

The steady-state tests also revealed 50-Hz oscillations of the H_2 control valve, which increased in amplitude with decreasing power. Investigative open and closed loop tests isolated the instability to malfunctioning of the hydrogen valve torque motor, and/or an improperly positioning LVDT in the hydrogen or oxygen flow control valve. Subsequent operation at zero-to-100 percent load and combustor temperature settings up to 1660 R caused no reduction in the instability.

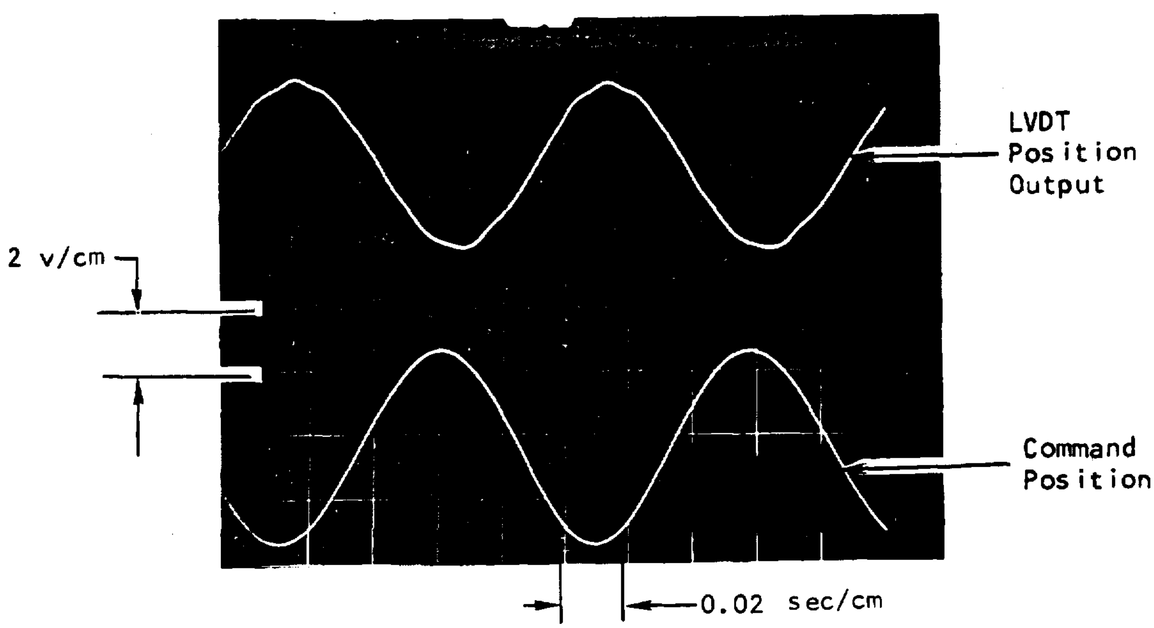
Open and closed tests to determine H_2 valve characteristics indicated that flow at low-flow conditions tended to close the valve, thereby requiring greater operating signals to obtain operating position resulting in a very high gain at high flows where the closing effect was less pronounced. Attempts to improve valve performance with increased spring rate indicated the torque motor could not fully open the valve. The torque motor was undersized. Its torque tube, which provided the restoring force for the actuating arm and also served to contain the H_2 gas pressure, failed repeatedly. The dry torque motor using a torque tube was then abandoned, and the valve was modified to be actuated by a rotary electric drive motor.

The electric-motor drive was a rare-earth-cobalt, dc-motor-type (see fig. 24). Subsequent tests showed that the electric-motor driven H_2 control valve maintained combustor temperature and turbine speed within acceptable limits. This valve configuration was used for the remainder of the program.

Test results of the electric-motor drive system are shown in figs. 81 through 84. The data show valve response to the command position faster than that of the O_2 valve, causing an increase in O/F ratio and turbine inlet overtemperature during a transient. This problem was solved by increasing the volume of piping between the valve and the combustor. The hydrogen valve



a. 0.1 Hz



Note:
- No flow
- Closed loop

b. 10 Hz

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Figure 81.--Response Tests on Electric-Motor Driven H_2 Flow Control Valve.

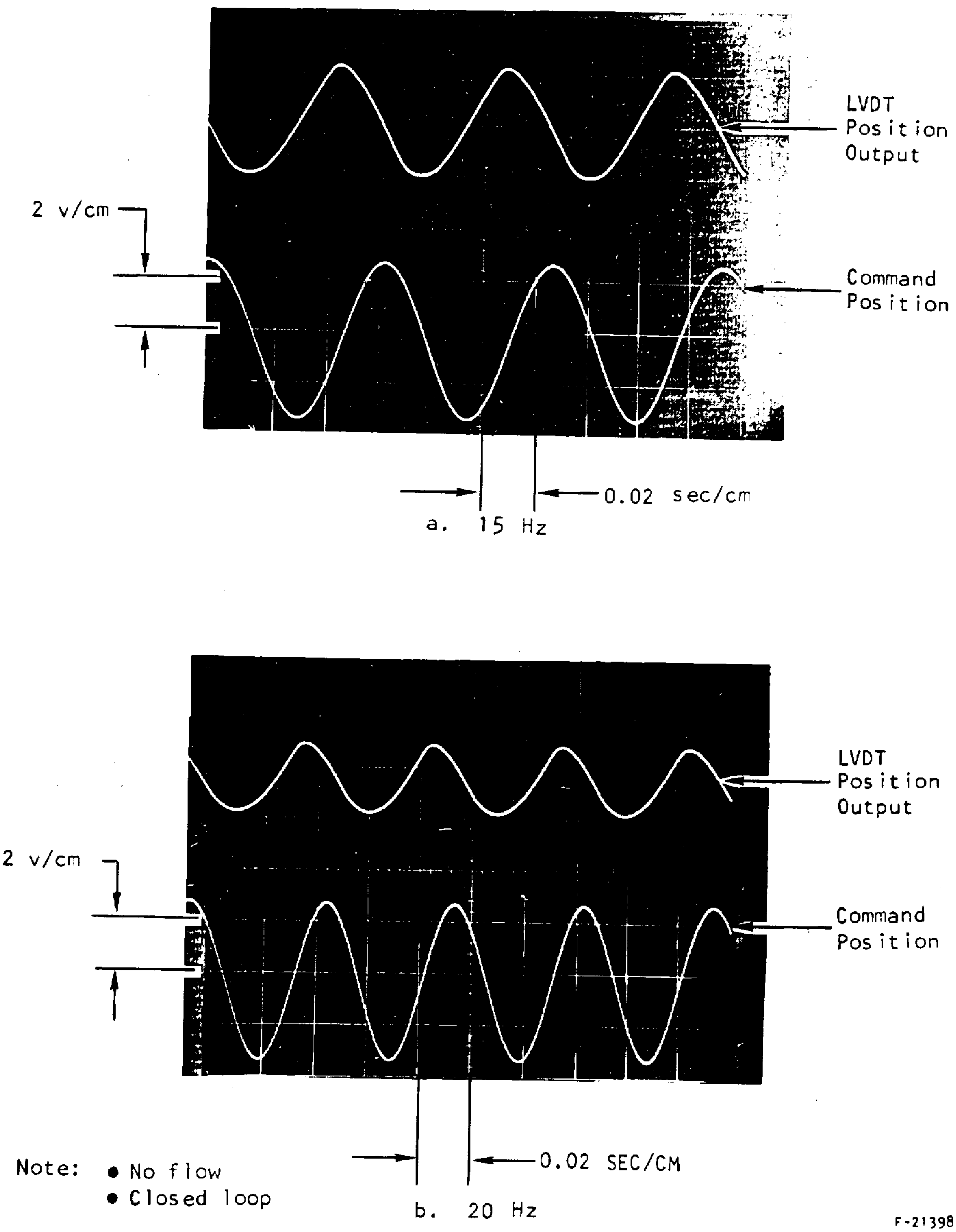

Figure 82.--Response Tests on Electric-Motor Driven H_2 Flow Control Valve.

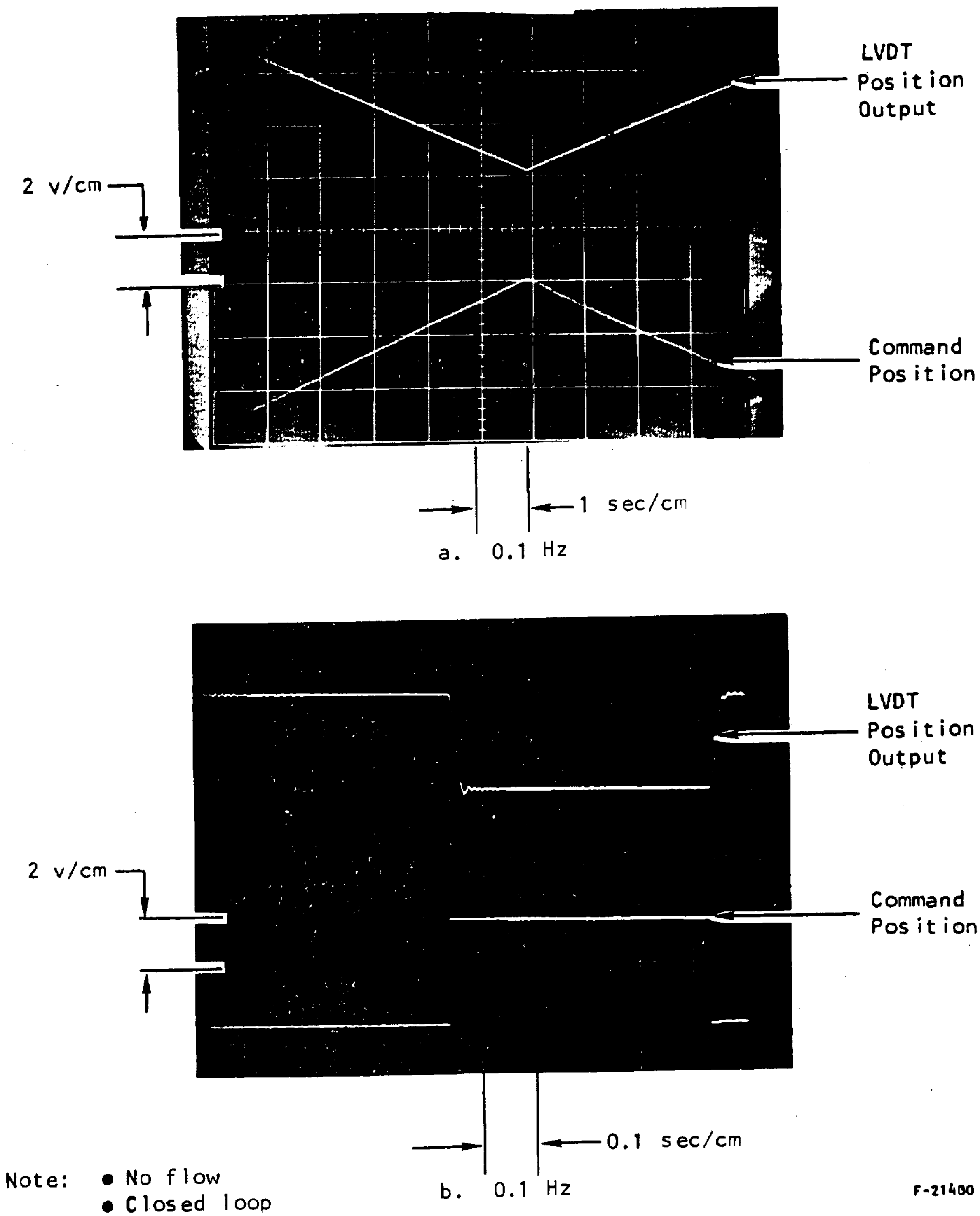

Figure 83.--Response Tests on Electric-Motor Driven H_2 Flow Control Valve.

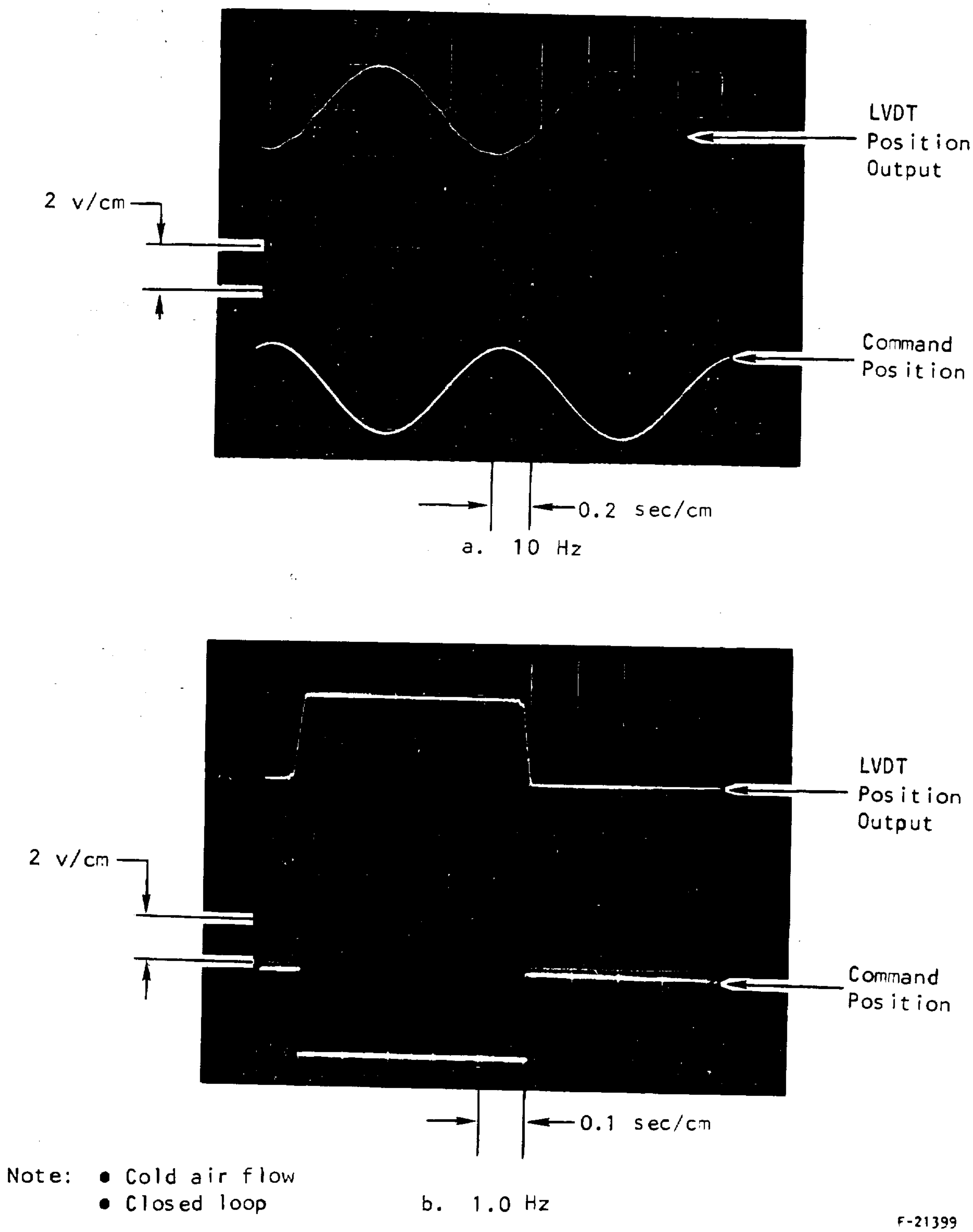

Figure 84.--Response Tests on Electric-Motor Driven H_2 Flow Control Valve.

was moved upstream about 15 in, which increased the blowdown time of the volume between the valve and the combustor, thereby decreasing the transient O/F ratio.

Control subsystem demonstration.--Steady-state operation of the revised control subsystem showed stable operation during 10-sec dwells at 0, 25, 50, 75, and 100 percent load. Thermocouples located in the simulated first-stage turbine nozzles read 1960 R during steady-state runs.

During transient operation with 25-percent load changes, the maximum variation in TIT was 78 R for the change from 25 to 0 percent load. Figures 85, 86, and 87 show the subsystem dynamic performance for 25-percent load changes: 0 to 25 to 0 percent, 25 to 50 to 25 percent, and 50 to 75 to 50 percent.

Control subsystem testing conducted from March through July 1974 accumulated 37 min run time and resulted in a subsystem capable of controlling the APU-T system.

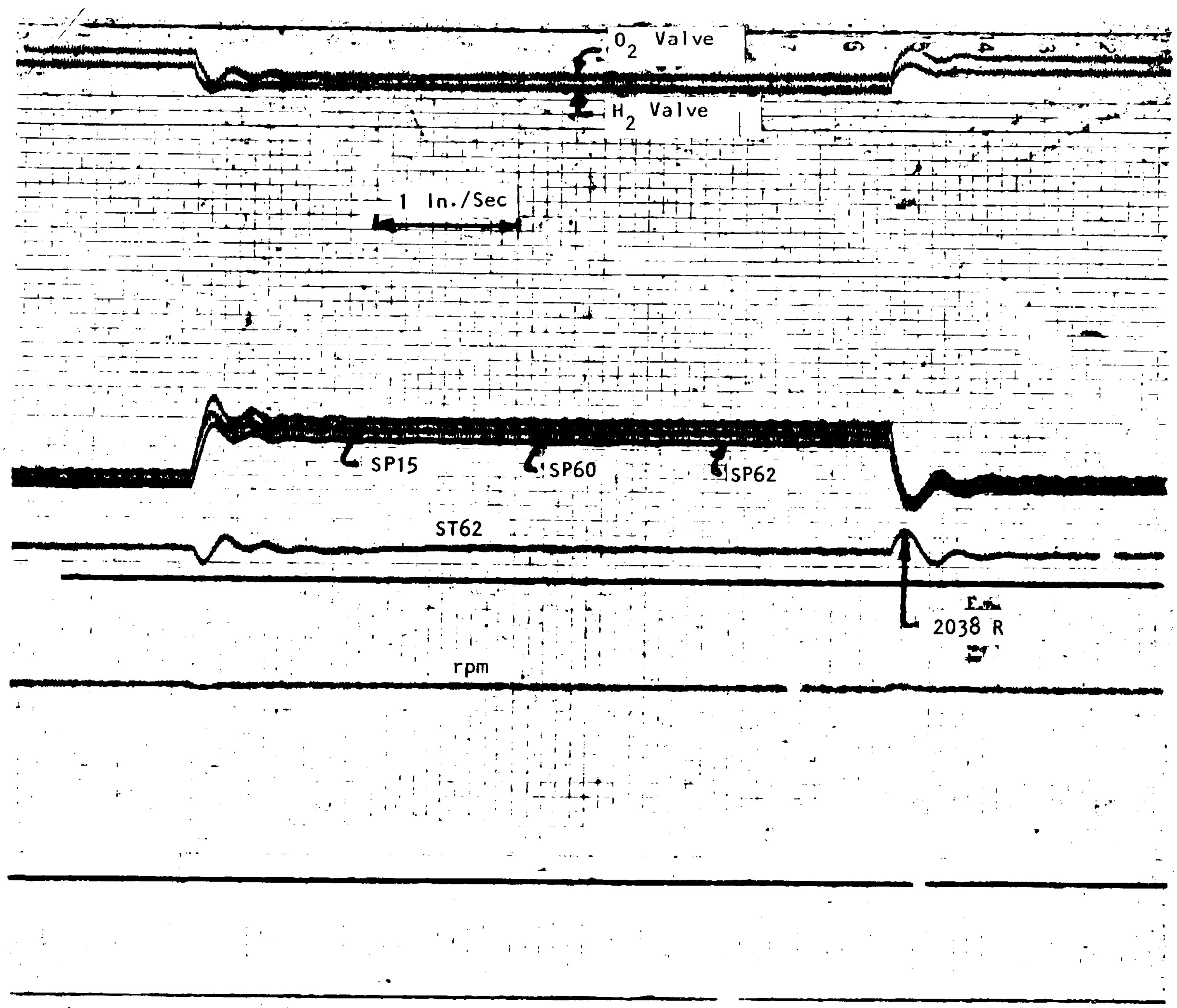

Figure 85.--Subsystem Run 239 -- 0 to 25 Percent Load.

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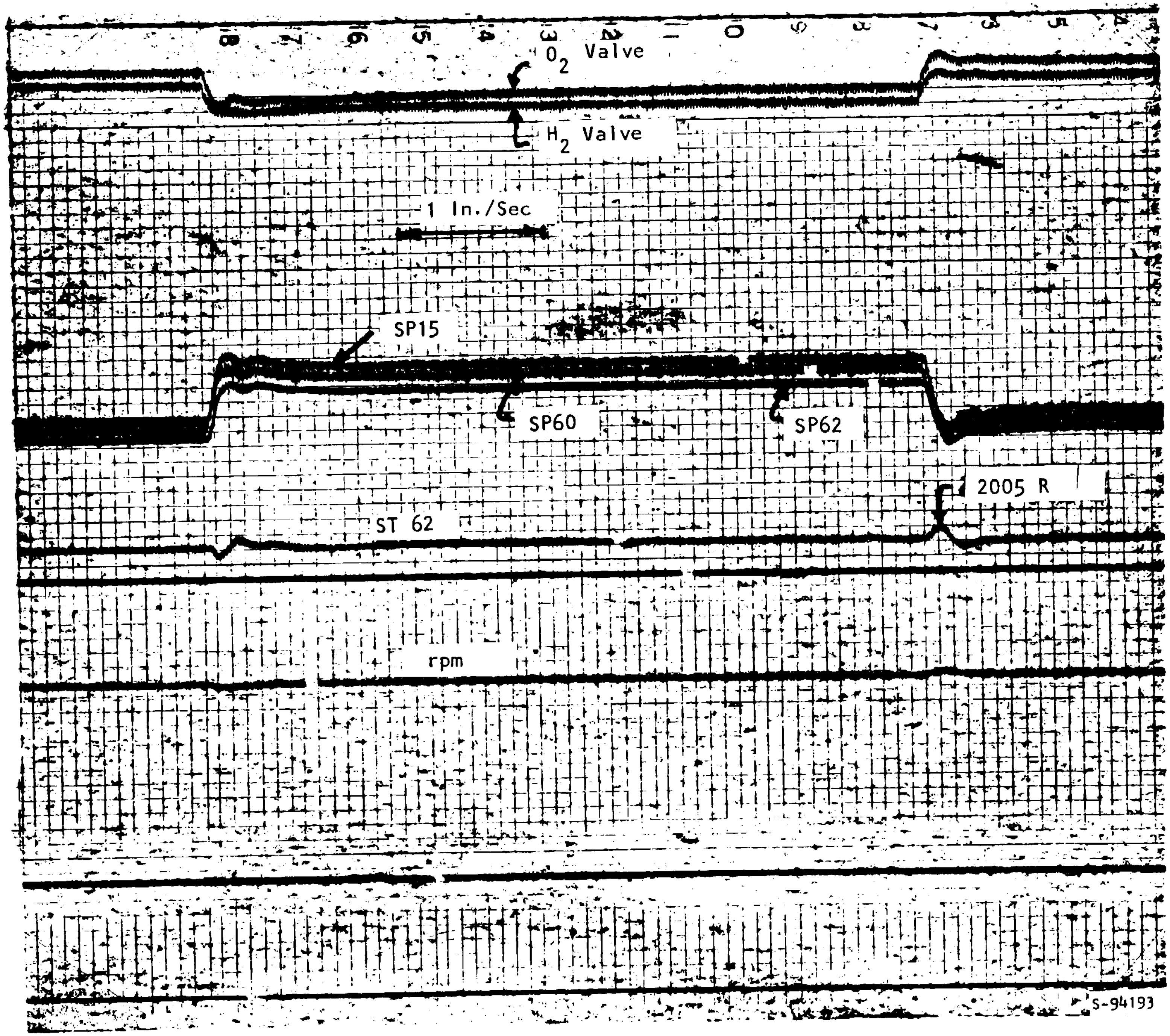


Figure 86.--Subsystem Run 239 -- 25 to 50 Percent Load.

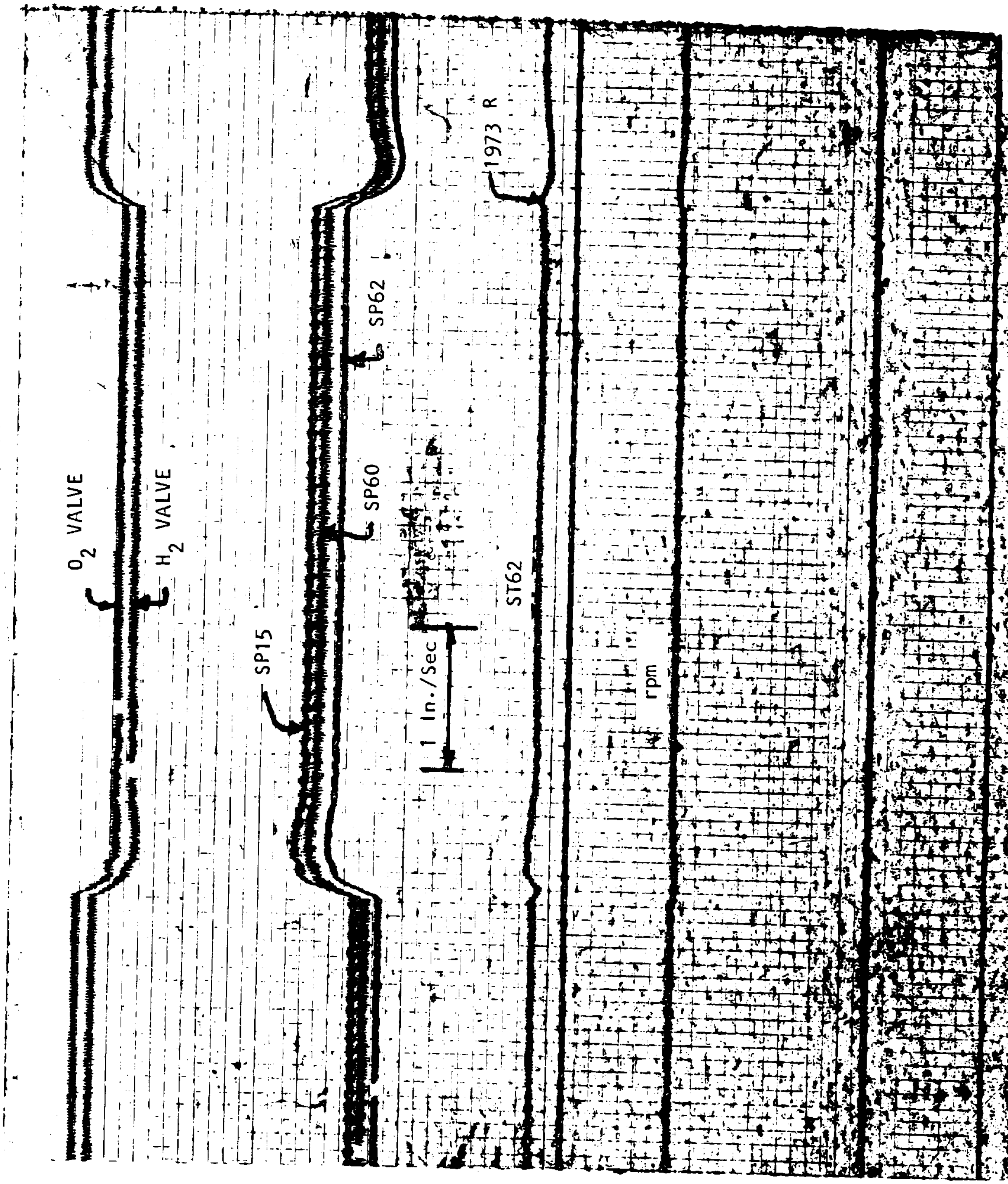


Figure 87.--Subsystem Run 239 -- 50 to 75 Percent Load.

APPENDIX B

DATA REDUCTION EQUATIONS

This appendix presents the calculations used to reduce the H_2-O_2 APU-T test data. Necessary curves used in the data reduction are presented following the equations.

Pertinent Equations

Ident No.	Equation	Data used	Units
101	Hydrogen weight flow $\dot{W}_{H_2} = \frac{60\ C_D\ A\ P_1}{\sqrt{RT_1}} \sqrt{\frac{2gK}{(K-1)} \left[\left(\frac{P_2}{P_1}\right)^{\frac{2}{K}} - \left(\frac{P_2}{P_1}\right)^{\frac{K+1}{K}} \right]}$ $A = (.2725)^2\ \pi/4 = 0.05832\ in.^2$ C_D = use curve 1 $K = 1.41$ $g = 32.174\ ft/sec^2$ $R = 772\ ft/\ R$ B = barometric pressure, $lb/in.^2$	P_1 = RP67 + B T_1 = RT67 If DH69 < 10 $P_2 = P_1$ - DL69 IF DH69 > 10 $P_2 = P_1$ - DH69	lb/min
102	Oxygen weight flow $\dot{W}_{O_2} = \frac{60\ C_D\ A\ P_1}{\sqrt{RT_1}} \sqrt{\frac{2gK}{K-1} \left[\left(\frac{P_2}{P_1}\right)^{\frac{2}{K}} - \left(\frac{P_2}{P_1}\right)^{\frac{K+1}{K}} \right]}$ $A = (.0905)^2\ \pi/4 = 0.006433\ in.^2$ C_D = use curve 2 $K = 1.40$ $g = 32.174\ ft/sec^2$ $R = 48.25\ ft/\ R$ B = barometric pressure, $lb/in.^2$	P_1 = RP66 ÷ B T_1 = RT66 If DH68 < 10 $P_2 = P_1$ - DL68 If DH68 > 10 $P_2 = P_1$ - DH68	lb/min
103	O/F ratio O/F = 102 / 101	Same as for 101 and 102	-

Pertinent Equations (Continued)

<table>
<tr><th>Ident No.</th><th>Equation</th><th>Data used</th><th>Units</th></tr>
<tr><td>104A</td><td>Pump or gearbox shaft horsepower
hp = f (G, T)

<table><tr><th><u>Criteria</u></th><th><u>G</u></th><th><u>hp</u></th></tr><tr><td>SQ19 < 4.5</td><td>-</td><td>a</td></tr><tr><td>SQ19 > 4.5, LQ2 < 20</td><td>SQ19</td><td>b</td></tr><tr><td>SQ19 > 4.5, LQ2 > 20 < 82</td><td>LQ2</td><td>c</td></tr><tr><td>SQ19 > 4.5, LQ2 > 82</td><td>LQ2</td><td>d</td></tr></table>
<u>hp equations</u>

a 31.5
b 2.065G + 30.7
c 2.367 G + 24.6
d 2.442(G-82) + 211.5
see 3A 3B 4

Note: Above equations valid at test points. Horsepower ambiguous near 82 gal/min.

Above only used up to run 184.

Past run 184 use following:

<u>hp equations</u>

a 27.6
b 2.170G + 27.6
c 2.323G + 24.5
d 2.237(G-82) + 213.5
see 3C 3D

These derived in similar manner to those in 4</td><td>T = LT2

G = LQ2 or SQ19 as defined from criteria</td><td>hp</td></tr>
<tr><td>105</td><td>Specific propellant consumption

$$SPC = \frac{101 + 102}{104A} \times 60$$</td><td>Same as for
101 102 104A</td><td>$\frac{lb}{hp\text{-}hr}$</td></tr>
</table>

Pertinent Equations (Continued)

Ident No.	Equation	Data used	units
106	Heat of rejection $hr = C_1 \dot{W}_{O_2}$ $C_1 = 6438$ Btu/lb $\dot{W}_{O_2} = (102)$	Same as for (102)	Btu/min
107	Turbine inlet molecular weight $MW = 2.016\ (1 + O/F) = 2.016\ (1 + (103))$	Same as for (103)	$\frac{lb}{lb\text{-}mol}$
160	Specific heat ratio $\gamma = f\ (O/F) = f\ ((103))$ use curve (7)	Same as for (103)	-
108	Turbine pressure ratio $PR = P_1/P_2$ B = barometric pressure	P_1 = SP62 + B P_2 = SP64 + B	-
109	Adiabatic head $H_{ad} = AT\left(\frac{\gamma}{\gamma+1}\right)$ $\frac{\gamma}{\gamma+1} = 1 - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = 1 - \left(\frac{1}{(108)}\right)^{\frac{(160)-1}{(160)}}$ $A = f\ (O/F) = f\ ((103))$ use curve (8)	Same as for (108) (160) T = ST62	ft
110	Turbine flow $\dot{W} = \dot{W}_{O_2} + \dot{W}_{H_2} = (101) + (102)$	Same as for (101) (102)	lb/min
111	Turbine input horsepower $hp = \frac{\dot{W}\ H_{ad}}{33\ 000} = \frac{(110) \times (109)}{33\ 000}$	Same as for (109) (110)	hp

Pertinent Equations (Continued)

Ident No.	Equation	Data used	Units
112	Lube oil flow $\dot{W} = G\rho$ $\rho = 10.195 - 3.511 \times 10^{-3} T$ from curve 5	G = SQ83 + SQ85 (turbine)(gearbox) T = ST17	lb/min
113	Heat rejection to lube oil $Q = (\dot{W}_T \Delta T_T C_{P_T} + \dot{W}_G \Delta T_G C_{P_G})$ $\dot{W}_T = SQ83\rho_T \quad \rho_T = 10.195 - 3.511 \times 10^{-3} T_T$ $C_{P_T} = 0.255 + 3.43 \times 10^{-4} \left(\frac{T_T + T}{2}\right)$ $\Delta T_T = T_T - T$ $\dot{W}_G = SQ85\rho_G$ $\rho_G = 10.195 - 3.511 \times 10^{-3} T_G$ $C_{P_G} = 0.255 + 3.43 \times 10^{-4} \left(\frac{TG + T}{2}\right)$ $\Delta T_G = T_G - T$ curve 5 or, $\dot{W}_G \Delta T_G C_{P_G} = 42.5 \times$ 159	SQ83 SQ85 T = ST17 T_T = ST84 T_G = ST86	Btu/min
114	Turbine horsepower (ΔT method) $hp = \frac{C_p}{42.5} \dot{W} \Delta T$ $C_p = f\ (O/F) = f$ (103) see 9 $\dot{W}$ = 110 $\quad \Delta T = T_{IN} - T_{OUT}$	Same as for 103 110 T_{IN} = ST62 T_{OUT} = ST65	hp
115	Turbine horsepower (mechanical method) hp = 104A + 113 /42.5	Same as for 104A 113	hp

Pertinent Equations (Continued)

Ident No.	Equation	Data used	Units
116	Turbine horsepower (heat rejection method) $hp = \frac{1}{42.5}(Q_G + Q_H)$ Q_G = 113 Q_H = 153 + Q_5 Q_5 = 144	Same as for 113 144 153	hp
117	Turbine efficiency (ΔT method) $\eta_T = \frac{100\ \Delta T}{T_1 \frac{Y}{Y+1}}$ $\Delta T = T_1 - T_2$ $\frac{Y}{Y+1}$ = see 109	T_1 = ST62 T_2 = ST65 Same as for 109	%
118	Turbine efficiency (mechanical method) $\eta_T = \frac{115}{111} \times 100$	Same as for 111 115	%
119	Turbine efficiency (heat rejection method) $\eta_T = \frac{116}{111} \times 100$	Same as for 111 116	%
120	Hydraulic hp $hp = \frac{G\ \Delta P}{1714}$ $\Delta P = P_{OUT} - P_{IN}$ G = SQ19 if LQ2 < 20 G = LQ2 if LQ2 > 20	P_{OUT} = LP1 P_{IN} = LP2 G = LQ2 or SQ19 as defined from criteria	hp

Pertinent Equations (Continued)

Ident No.	Equation	Data used	Units
121	APU mechanical losses		hp
121B	hp = (111) x (118)/100 - (104A) = (113) /42.5		
121D	hp = (114) - (104A) = $(W\ C_P\ \Delta T)_{turbine}$ - pump shp		
121E	hp = (111) x (118)/100 - (122) = pump shp + heat rejection to lube oil hp - pump shp from heat rejection from hydraulic oil to H_2O		
121F	hp = (114) - (122) = $(W \cdot C_P\ \Delta T)_{turbine}$ - heat rej. to H_2O hp		
122	Pump shaft hp (oil heating method) hp = $Q_H/42.5$ Q_H = (144) + (153)	Same as for (144) (153)	hp
123	Hydraulic flow rate through cooler $\dot{W} = G\rho$ $\rho = 9.55 - 0.004T$ from curve (6)	T = LT2 G = SQ19	lb/min
124	Recuperator cold side flow $\dot{W}_R = \left(\frac{T_3 - T_1}{T_2 - T_1}\right) \dot{W}_{H_2}$ $\dot{W}_{H_2}$ = (101)	T_1 = ST45 T_2 = ST47 T_3 = ST51 (101)	lb/min
125	Recuperator bypass flow $\dot{W}_B$ = (101) - (124)	(101) (124)	lb/min

Pertinent Equations (Continued)

Ident No.	Equation	Data used	Units
126	Preheater hot side flow $\dot{W}_P = \frac{(T_1 - T_3)}{(T_1 - T_2)} \dot{W}_{H_2}$ $\dot{W}_{H_2}$ = (101)	T_1 = ST51 T_2 = ST56 T_3 = ST57 (101)	lb/min
127	Preheater bypass flow $\dot{W}_B$ = (101) - (126)	(101) (126)	lb/min
128	Heat exchanger effectiveness HX #1 (preheater) Cold side eff. $= \frac{T_2 - T_1}{T_3 - T_1}$	T_1 = ST27 T_2 = ST31 T_3 = ST51 T_4 = ST56	-
129	Hot side eff. $= \frac{T_3 - T_4}{T_3 - T_1}$		
130	HX #3 (regenerator) Cold side eff. $= \frac{T_2 - T_1}{T_3 - T_1}$	T_1 = ST31 T_2 = ST35 T_3 = ST39 T_4 = ST41	-
131	Hot side eff. $= \frac{T_3 - T_4}{T_3 - T_1}$		
132	HX #5 (hydraulic oil cooler) Cold side eff. $= \frac{T_2 - T_1}{T_3 - T_1}$	T_1 = ST35 T_2 = ST39 T_3 = ST18 T_4 = ST19	-
133	Hot side eff. $= \frac{T_3 - T_4}{T_3 - T_1}$		

Pertinent Equations (Continued)

Ident No.	Equation	Data used	Units
134	HX #6 (lube oil cooler)	T_1 = ST41	-
	Cold side eff. = $\dfrac{T_2 - T_1}{T_3 - T_1}$	T_2 = ST45	
		T_3 = ST16	
135	Hot side eff. = $\dfrac{T_3 - T_4}{T_3 - T_1}$	T_4 = ST17	
136	HX #8 (recuperator)	T_1 = ST45	-
	Cold side eff. = $\dfrac{T_2 - T_1}{T_3 - T_1}$	T_2 = ST47	
		T_3 = ST65	
137	Hot side eff. = $\dfrac{T_3 - T_4}{T_3 - T_1}$	T_4 = ST66	
138	HX #9 (equalizer)[a]	T_1 = ST57	-
	Cold side eff. = $\dfrac{T_2 - T_1}{T_3 - T_1}$	T_2 = ST58	
		T_3 = ST5	
139	Hot side eff. = $\dfrac{T_3 - T_4}{T_3 - T_1}$	T_4 = ST7	
140	Q HX #1 (preheater)	T_1 = ST27	Btu/min
	Cold side	T_2 = ST31	
	$Q = (h_2 - h_1)\, \dot{w}_h$	101	
	$h_1 = f\,(T_1, P_1)$ see 10		
	$h_2 = f\,(T_2, P_2)$		
	assume $P_1 = P_2 = 550$ psia w_h = 101		

[a]On equalizer, hot side is actually the colder.

Pertinent Equations (Continued)

Ident No.	Equation	Data used	Units
141	Q HX #1 (preheater) Hot side $Q = (h_3 - h_4) \cdot \dot{w}_h$ $h_3 = f(T_3, P_3)$ see 10 $h_4 = f(T_4, P_4)$ assume $P_3 = P_4 = 550$ psia $\dot{w}_h =$ 126	126 T_3 = ST51 T_4 = ST56	
142	Q HX #3 (regenerator) Cold side $Q = (h_2 - h_1)\ \dot{w}_h$ $h_1 = f(T_1, P_1)$ $h_2 = f(T_2, P_2)$ assume $P_1 = P_2 = 550$ psia $\dot{w}_h =$ 101	T_1 = ST31 T_2 = ST35 101	Btu/min
143	Q HX #3 (regenerator) hot side $Q = (h_3 - h_4)\ \dot{w}_h$ $h_3 = f(T_3, P_3)$ see 10 $h_4 = f(T_3, P_4)$ assume $P_3 = P_4 = 550$ psia $\dot{w}_h =$ 101	T_3 = ST39 T_4 = ST41 101	Btu/min

Pertinent Equations (Continued)

Ident No.	Equation	Data used	Units
144	Q Hx #5 (hydraulic oil cooler)	T_1 = ST35	Btu/min
	Cold side	T_2 = ST39	
	$Q = (h_2 - h_1)\ \dot{w}_h$	101	
	$h_1 = f\ (T_1, P_1)$ 10		
	$h_2 = f\ (T_2, P_2)$		
	assume P_1, P_2 = 550 psia		
	$\dot{w}_h$ = 101		
145	Hot side	T_3 = ST18	
	$Q = (T_3 - T_4)\ \dot{w}_0\ C_{P_0}$	T_4 = ST19	
	$\dot{w}_o$ = 123	123	
	$C_{P_0} = 0.221 + 6.02 \times 10^{-4} \left(\frac{T_3 + T_4}{2}\right)$		
	see 6		
146	Q Hx #6 (lube oil cooler)	T_1 = ST41	Btu/min
	Cold side	T_2 = ST45	
	$Q = (h_2 - h_1)\ \dot{w}_h$	101	
	$h_1 = f\ (T_2, P_1)$ see 10		
	$h_2 = f\ (T_2, P_2)$		
	assume $P_1 = P_2$ = 550 psia		
	$\dot{w}_h$ = 101		

Pertinent Equations (Continued)

Ident No.	Equation	Data used	Units
147	Q Hx #6 (lube oil cooler) Hot side $Q = (T_3 - T_4)\, \dot{w}_o\, Cp_0$ $\dot{w}_o$ = (112) $Cp_0 = 0.255 + 3.43 \times 10^{-4} \left(\frac{T_3 + T_4}{2}\right)$ 5	T_3 = ST16 T_4 = ST17 (112)	Btu/min
148	Q Hx #8 (recuperator) Cold side $Q = (h_2 - h_1)\, \dot{w}_R$ $h_1 = f\,(T_1, P_1)$ $h_2 = f\,(T_2, P_2)$ see (10) assume $P_1 = P_2$ = 550 psi $\dot{w}_R$ = (124)	T_1 = ST45 T_2 = ST47 (124)	Btu/min
149	Q Hx #8 (recuperator) Hot side $Q = (T_3 - T_4)\, \dot{w}_m\, c_p$ $\dot{w}_m$ = (101) + (102) $c_p = \left(\frac{c_{p_3} + c_{p_4}}{2}\right)$	T_3 = ST65 T_4 = ST66 (101) (102) (103)	Btu/min

Pertinent Equations **(Continued)**

Ident No.	Equation	Data used	Units
149 Cont.	$c_{P_3} = 0.9857 \dfrac{\frac{\gamma}{\gamma - 1}}{1 + O/F}$ $c_{P_4} = 0.9857 \dfrac{\frac{k}{k-1}}{1 + O/F}$ $\gamma = f\ (T_3)$ see 9 $k = f\ (T_4)$ $O/F =$ 103		
150	Q Hx #9 (equalizer) Cold side $Q = (h_2 - h_1)\ \dot{w}_h$ $h_1 = f\ (P_1, T_1)$ see 10 $h_2 = f\ (P_2, T_2)$ assume $P_1 = P_2 = 550$ psia $\dot{w}_h =$ 101	T_1 = ST57 T_2 = ST58 101	Btu/min
151	Hot side If $T_3 > 500$ R; $Q = (T_3 - T_4)\ \dot{w}_0\ c_{P_0}$ $\dot{w}_0 =$ 102 $c_{P_0} = 0.24$	102 T_3 = ST5 T_4 = ST7	Btu/min

Pertinent Equations (Continued)

Ident No.	Equations	Data used	Units
151 Cont.	if $T_3 < 500$ R; $Q = (h_3 - h_4)\ \dot{w}_0$ $h_3 = f\ (T_3, P_3)$ see (11) $h_4 = f\ (T_4, P_4)$ (assume $P_3 = P_4 = 900$ psia) $\dot{w}_o$ = (102)		
152	System heat rejection Q = (153) + (154)	(153) and (154)	Btu/min
153	Hydr oil/water Hx heat transfer $Q = \dot{w}_w\ C_P\ \Delta T_w$ $\Delta T_w = T_2 - T_1$ $\dot{w}_w = 8.34\ G$ $C_p = 1.00$	T_1 = LT5 T_2 = LT6 G = LQ5	Btu/min
154	Exhaust heat rejection $Q = \dot{w}_m\ C_p\ T$ w_m = (101) + (102) $C_p = 0.9857\ \dfrac{\frac{\gamma}{(\gamma-1)}}{1+O/F}$ $\gamma = f\ (T)$ (9)	(101) and (102) T = ST66	Btu/min

Pertinent Equations (Continued)

Ident No.	Equation	Data used	Units
155	Theoretical combustion temperature $T_C = f\ (T_1,\ O/F)$ $= (T_1 - 530) + 586 + 1714\ (O/F)$ $T_C = T_1 + 56 + (1714 \times 103)$ Note: This is an approximate value	T_1 = ST58 103	^{o}R
156	Characteristic velocity, C* $C^* = \dfrac{PAg\ 60}{\dot{w}}$ $P = P_1 + B$ B = barometric pressure A = turbine first-stage nozzle effective throat area = 0.1517 $in.^2$ (in system tests) $g = 32.174\ ft/sec^2$ $\dot{w}$ = 110	P_1 = SP62 110	ft/sec
157	Theoretical C* $C^* \approx \dfrac{g\sqrt{T}}{\sqrt{\dfrac{g\gamma}{R}\left(\dfrac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}}}$ $g = 32.174\ ft/sec^2$ T = 155 $\gamma = f\ (O/F,\ T)$ see curve 9 $R = f\ (O/F) = 1544/107$	107 and 155	ft/sec

Pertinent Equations (Continued)

Ident No.	Equation	Data used	Units
158	C* efficiency $\eta_{C*} = ((156) / (157)) \times 100$	(156) (157)	%
159	Gearbox losses (oil heating method) $h_p = \frac{\dot{w}_G \Delta T_G\ C_{PG}}{42.5}$ $\dot{w}_G = SQ85\ \rho_G$ $\rho_G = 10.195 - 3.511 \times 10^{-3}\ T_G$ $C_{PG} = 0.255 + 3.43 \times 10^{-4} \left(\frac{T_G + T}{2}\right)$ $\Delta T_G = T_G - T$ see curve (5)	T_G = ST86 T = ST17 SQ85	hp
160	Specific heat ratio See page 3		
161	Effective throat area of turbine nozzle $C_D A = \frac{W\sqrt{T}}{60P\sqrt{\frac{\gamma g MW}{1544}\left(\frac{\gamma+1}{2}\right)^{\frac{\gamma+1}{2(1-\gamma)}}}}$ γ = (160) g = 32,174 ft/sec^2 W = (110) $P = P_1 + B$ B = barometric pressure $T = T_1$ MW = (107)	P_1 = SP62 T = ST62 (107) (110) (160)	in.^{2}

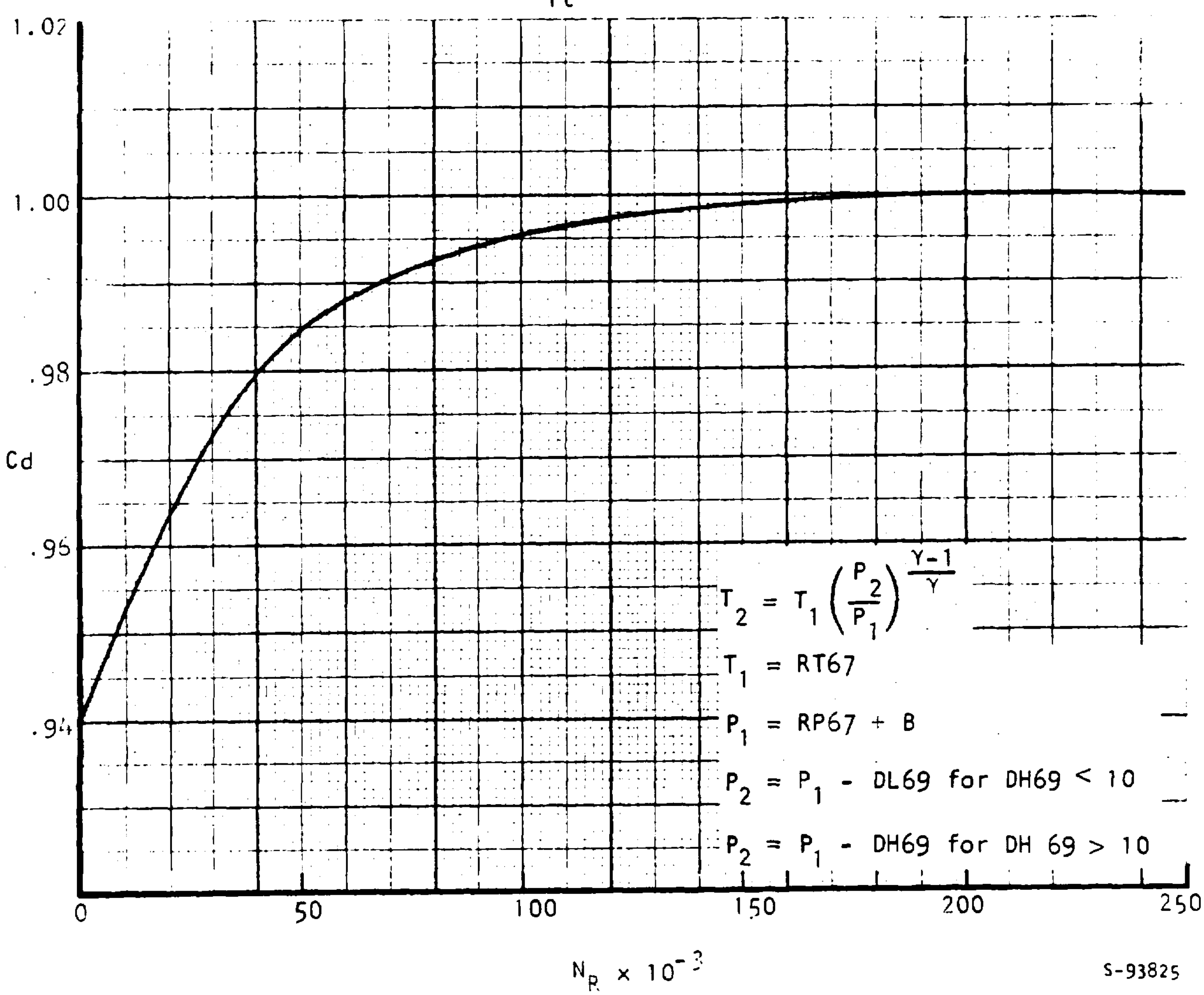
$$N_R = \frac{Vd\rho}{\mu}$$

$$V = 412.1 \sqrt{T_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{.291}\right]} \quad \text{ft/sec}$$

$$d = \frac{0.2725}{12} = 0.02271 \quad \text{ft}$$

$$\rho = \frac{.00561}{32.2} \; \frac{P_2}{14.7} \; \frac{492}{T_2} = 0.00583 \frac{P_2}{T_2} \qquad \frac{\text{lb-sec}^2}{\text{ft}^4}$$

$$\mu = 0.08 \times 10^{-5} \; \frac{\text{lb-sec}}{\text{ft}^2} \quad (530 \text{ R})$$



(1) Venturi Discharge Coefficient NASA
V6 Venturi with H_2

$$N_R = \frac{Vd\rho}{\mu}$$

$$V = 104.26 \sqrt{T_1 \left[1 - \left(\frac{P_2}{P_1} RP6\right)^{.286}\right]} \quad \text{ft/sec}$$

$$d = \frac{0.0905}{12} = 0.007542 \text{ ft}$$

$$\rho = \frac{.08921}{32.2} \frac{P_2}{14.7} \frac{492}{T_2} = 0.09273 \frac{P_2}{T_2} \quad \frac{\text{lb-sec}^2}{\text{ft}^4}$$

$$\mu = 0.042 \times 10^{-5} \frac{\text{lb-sec}}{\text{ft}^2} \quad (530 \text{ R})$$

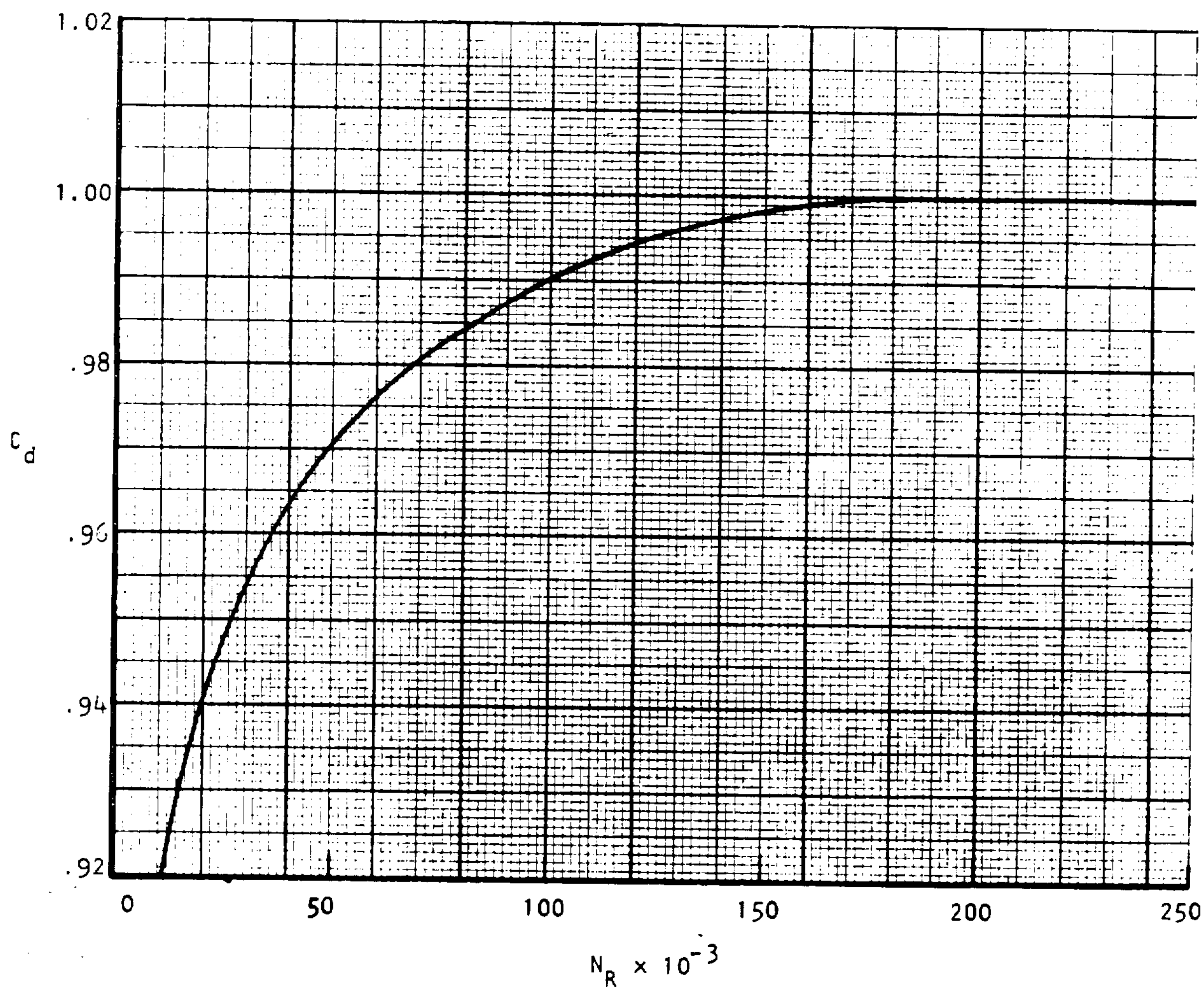
$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

T_1 = RT66

P_1 = RP66 ÷ B

$P_2 = P_1$ - DL68 for DH68 < 10

$P_2 = P_1$ - DH68 for DH68 > 10



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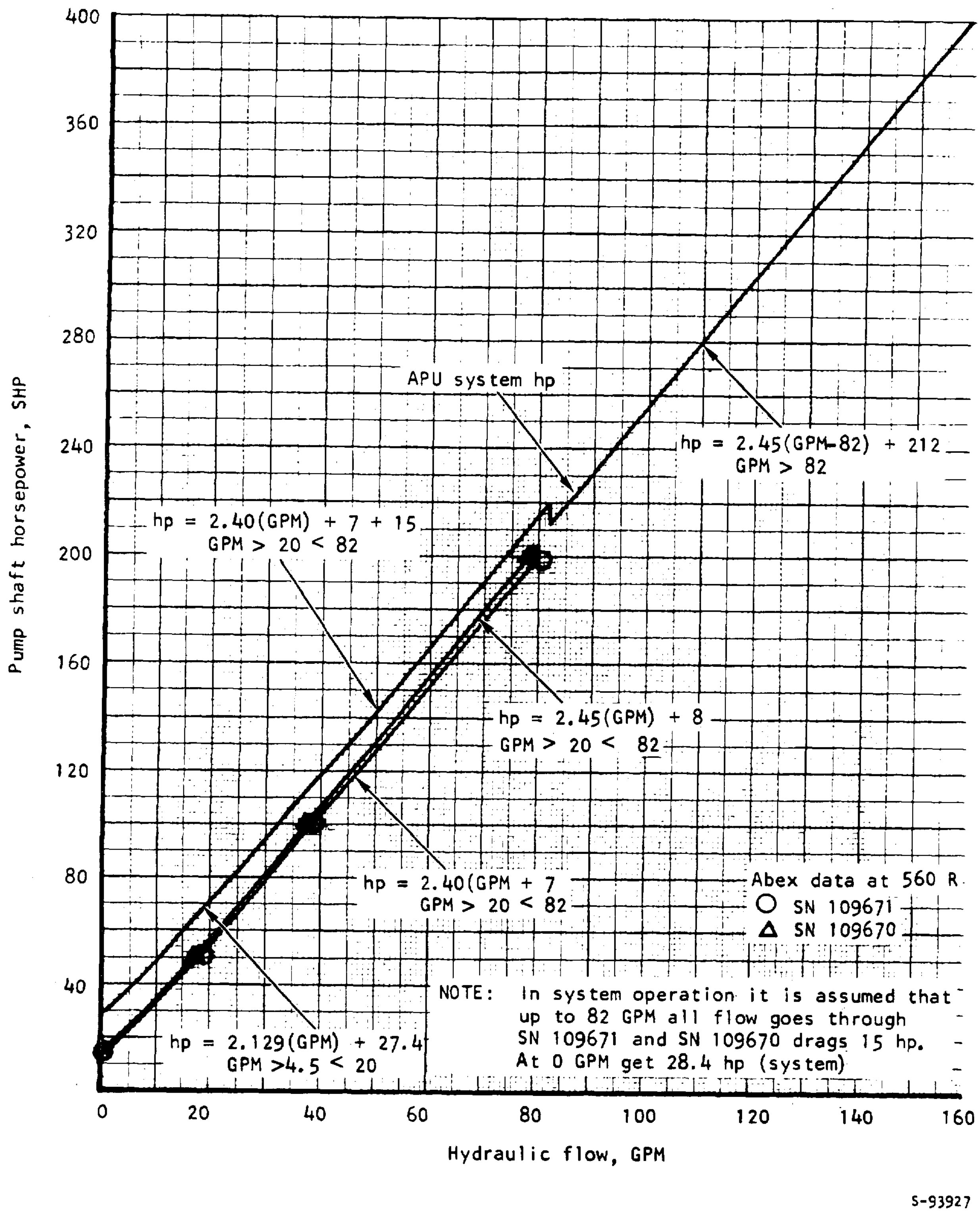
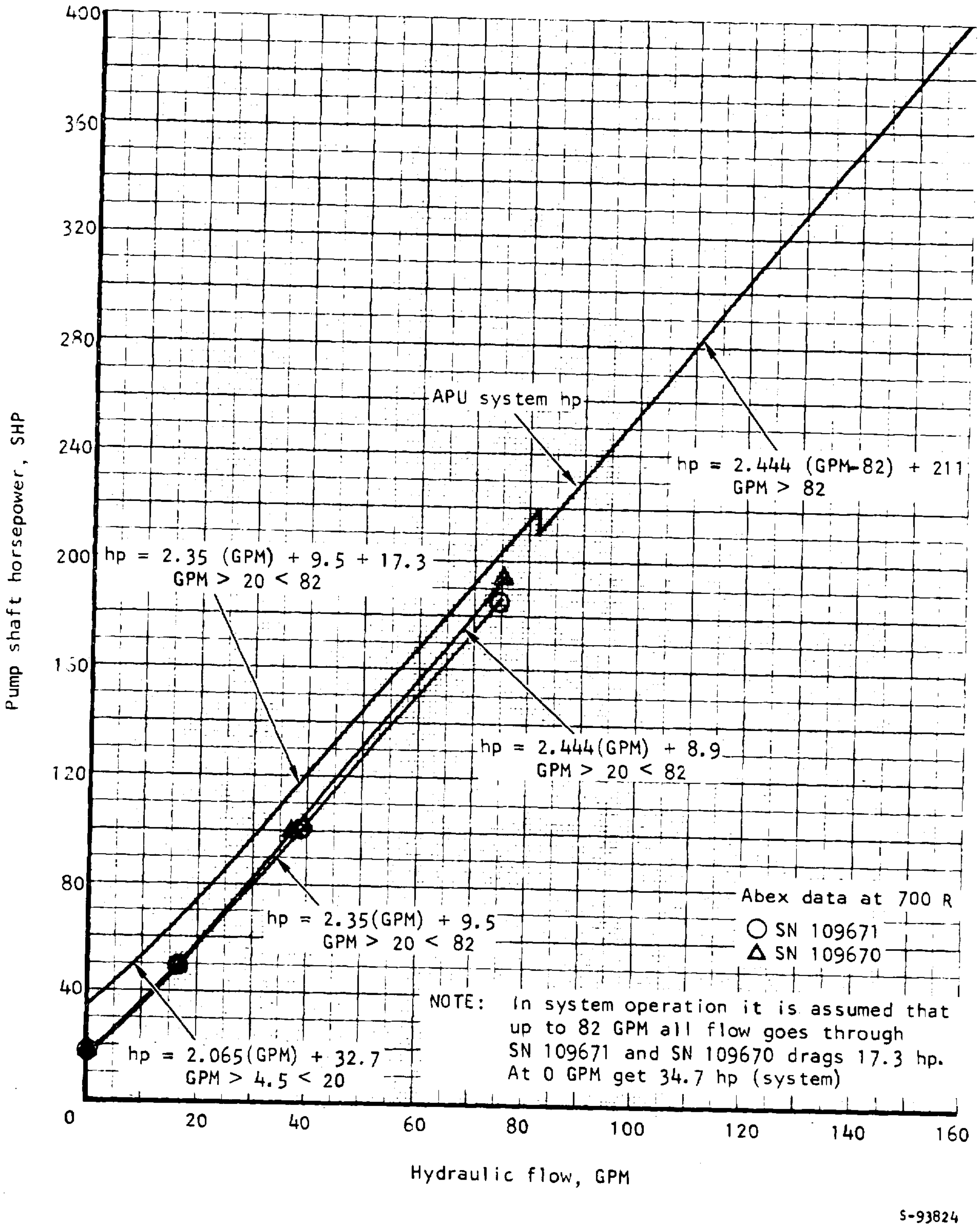
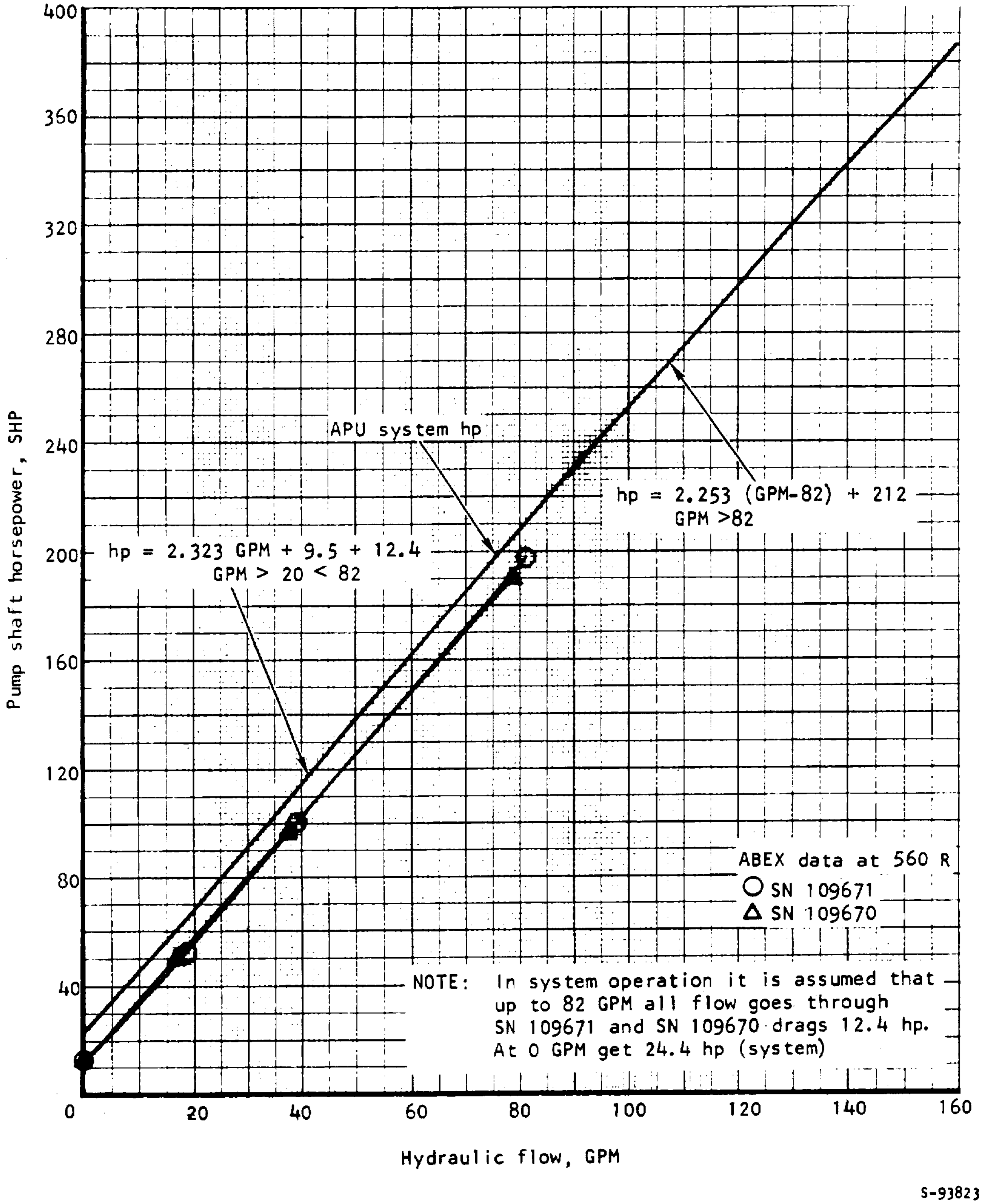
(2) Venturi Discharge Coefficient NASA V5 Venturi with O_2



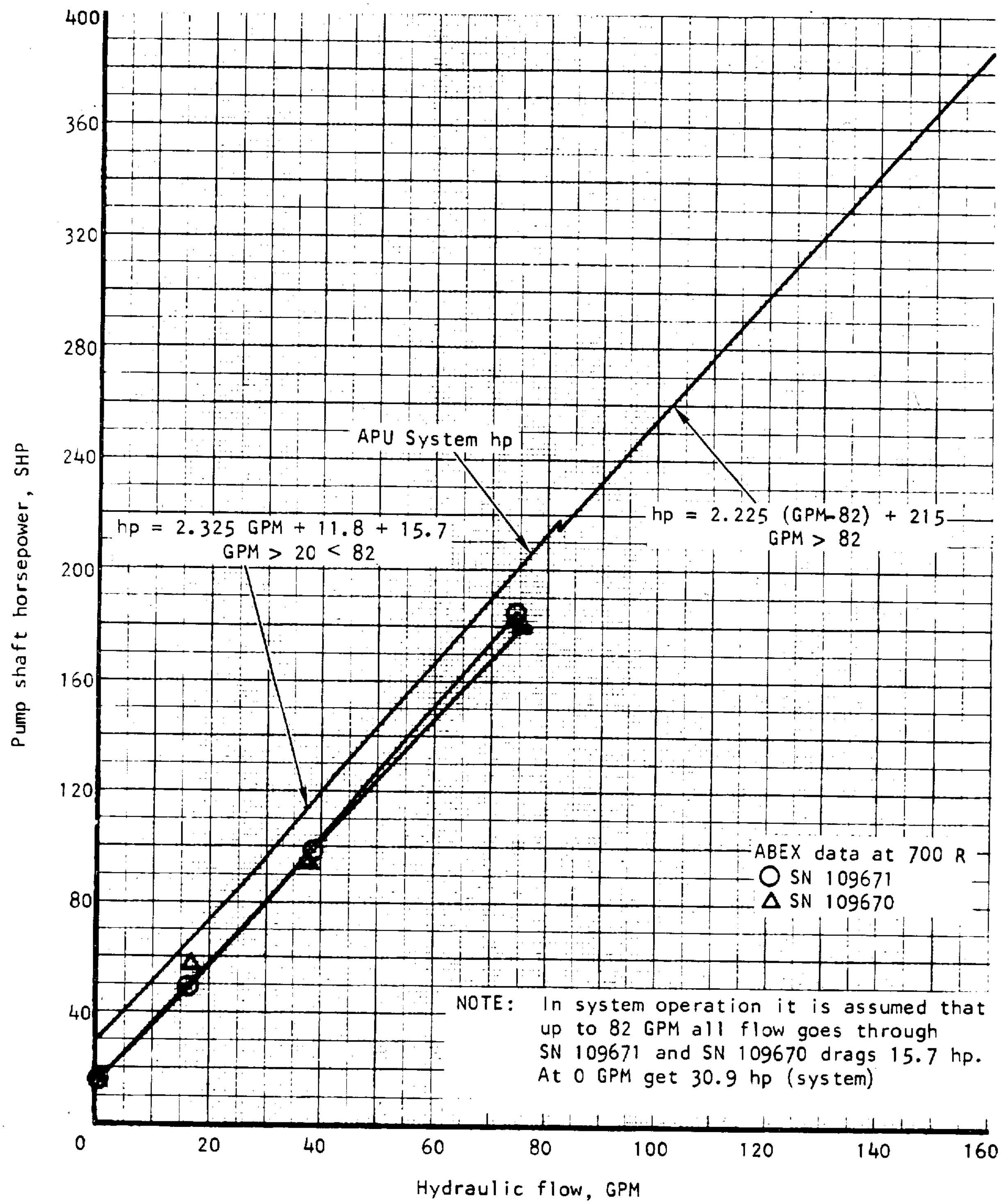
(3A) Calibration of AP27V-3-02 Hydraulic Pumps



(3B) Calibration of AP27V-3-02 Hydraulic Pumps



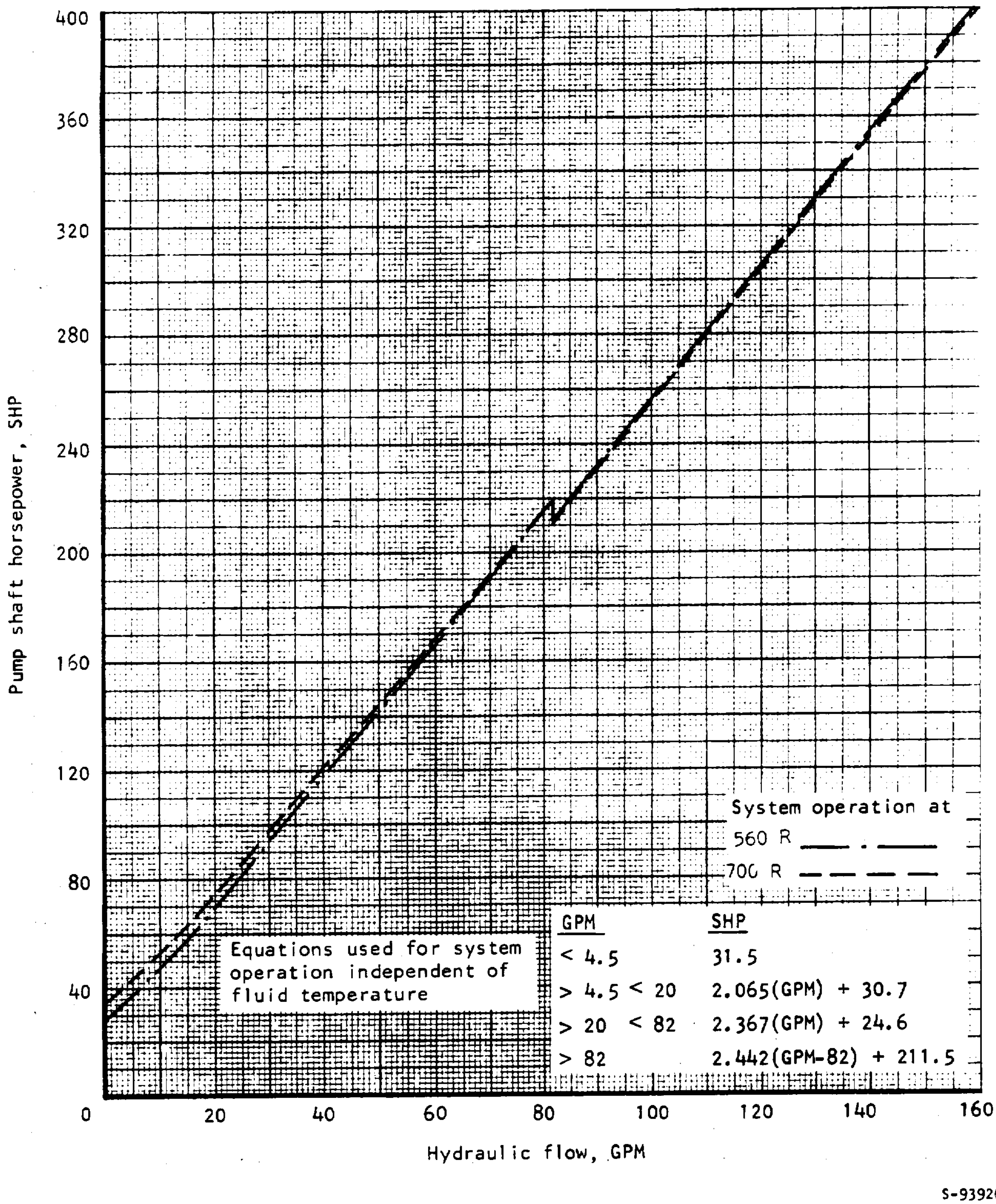
3C Calibration of Repaired AP27V-3-02 Hydraulic Pumps



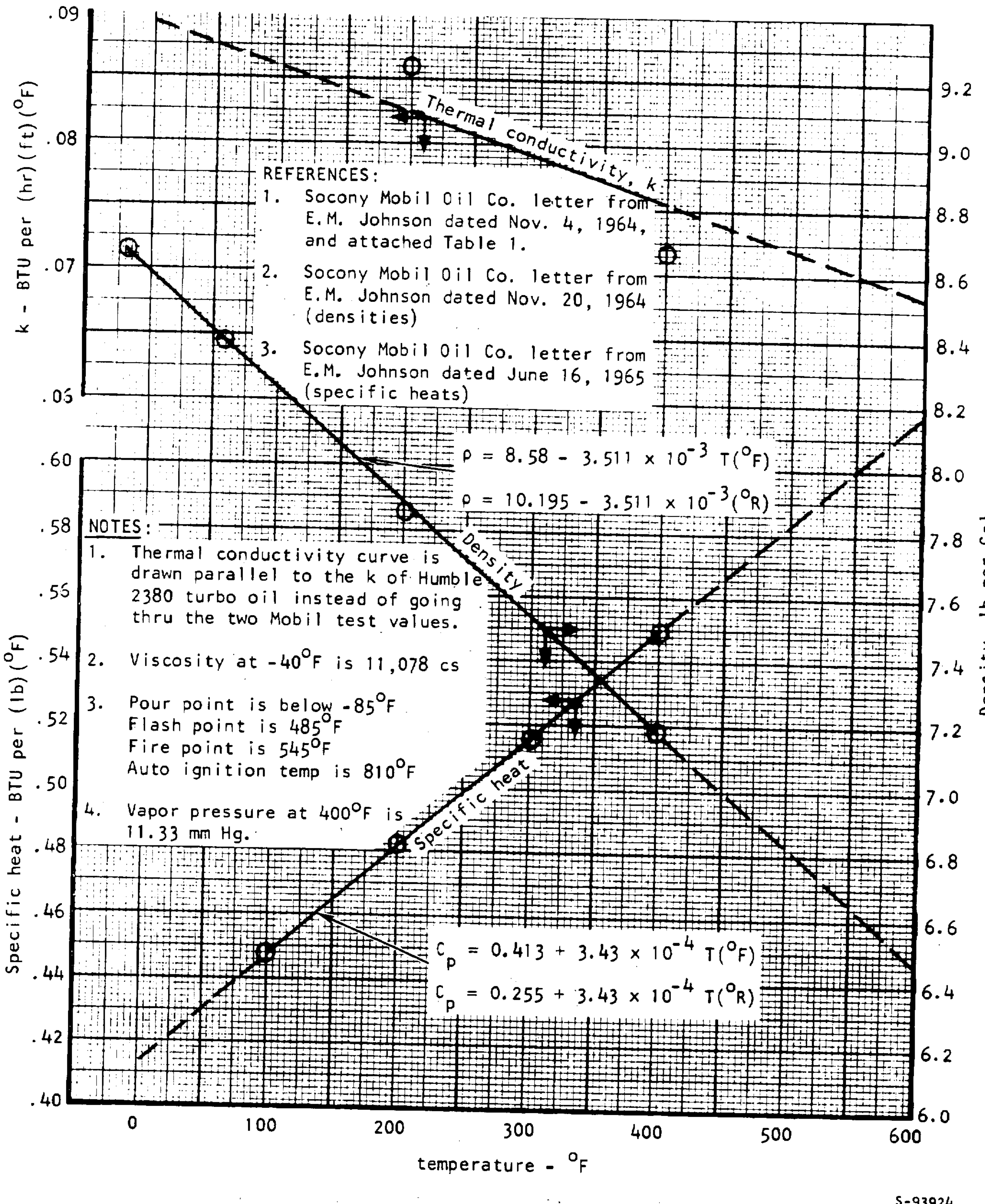
S-93822

(3D) Calibration of Repaired AP27V-3-02 Hydraulic Pumps

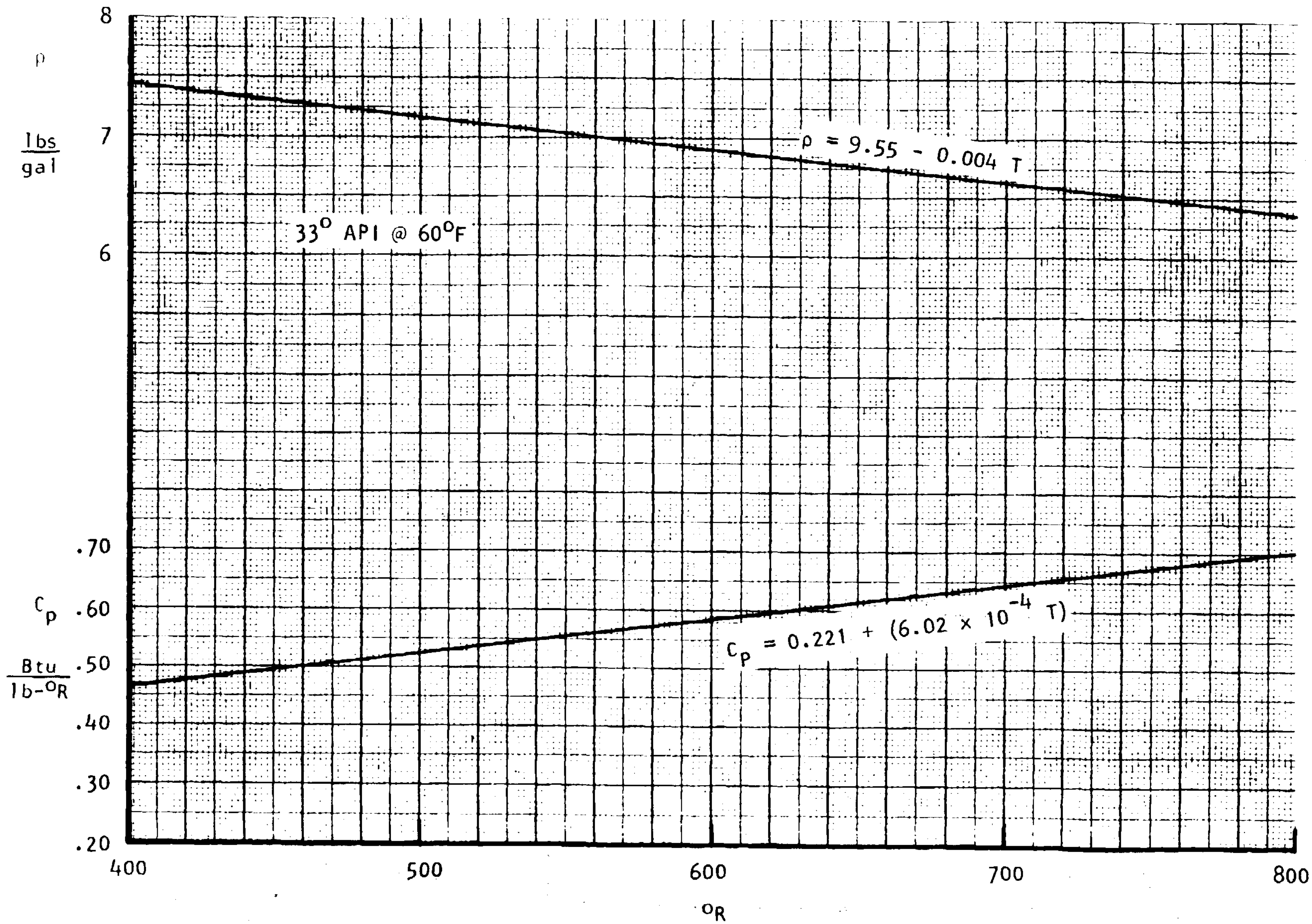
C-3



(4) System Operation With AP27-3-02 Hydraulic Pumps

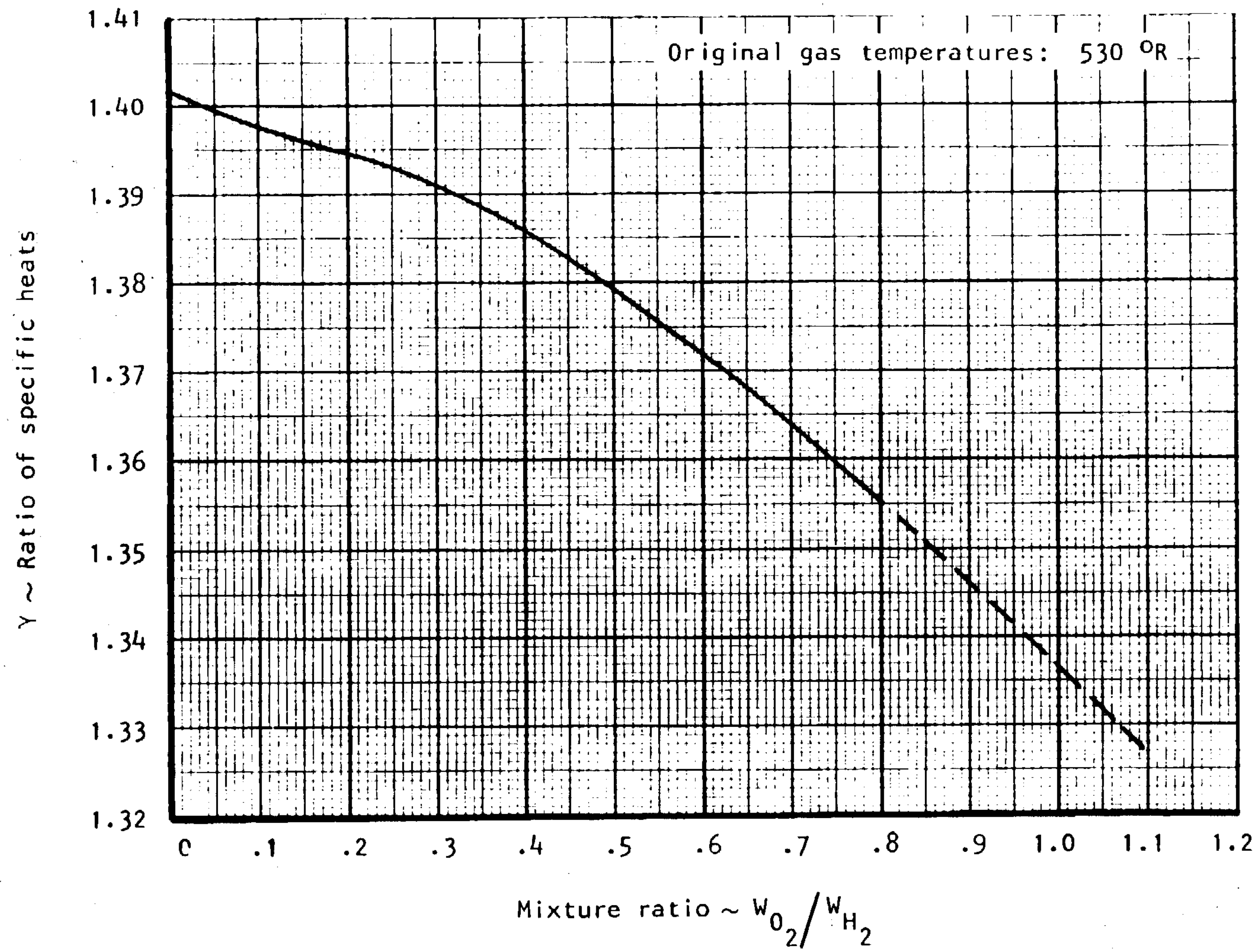


(5) Typical Properties of Mobil Jet Oil II (a MIL-L-23699 Oil)



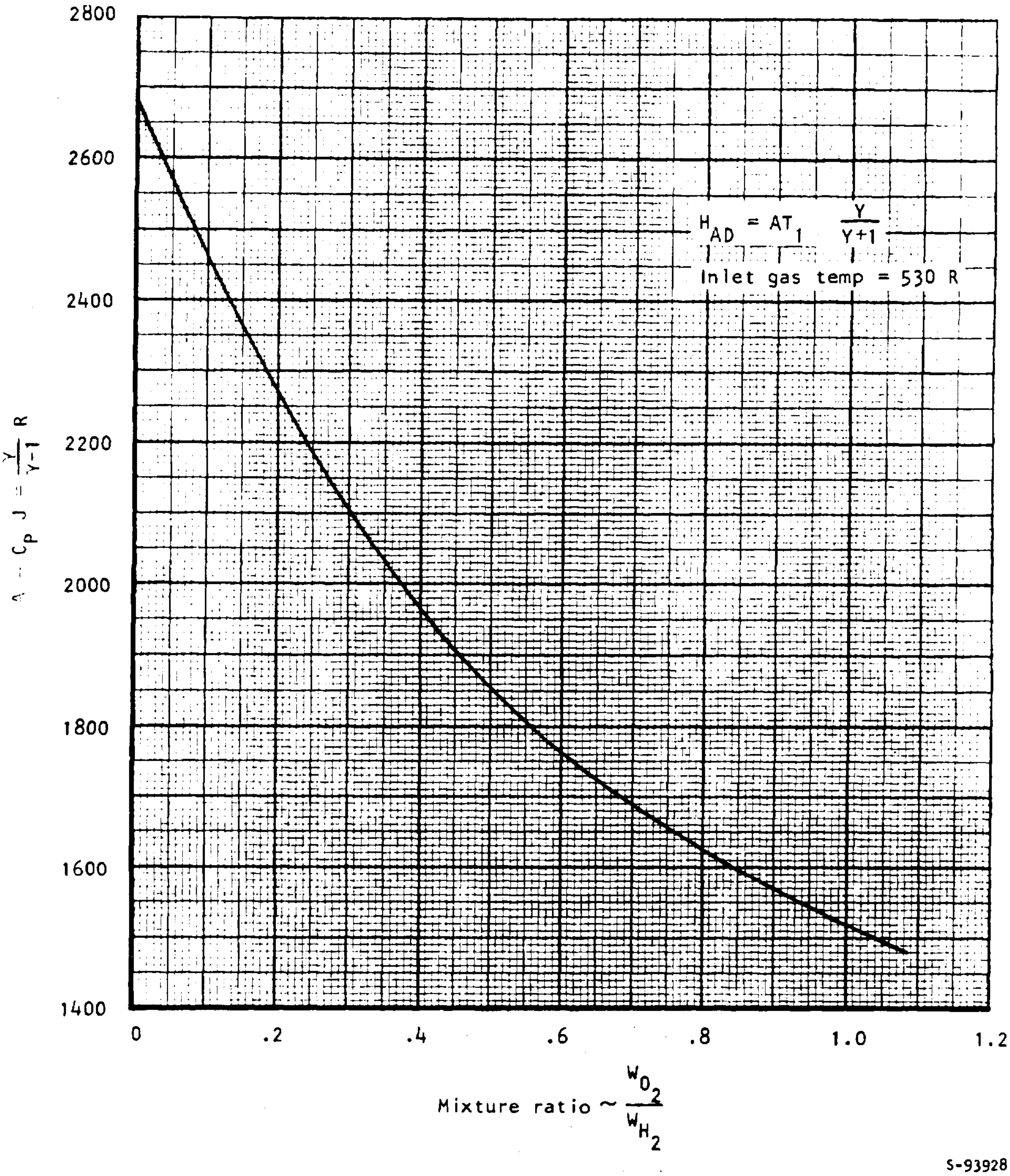
S-93920

(6) Density and Specific Heat of MIL-H-5606



S-93919

(7) Ratio of Specific Heats Combusted Hydrogen



(8) Constant "A" for Combusted Hydrogen

9

γ vs O/F and T(^{o}R)

Steam + H_2

ref: NASA SP273
1 atm

O/F \ T	700	1000	1200	1400	1600	1800	2000	2200	2400
0.4	1.3947	1.3900	1.3870	1.3828	1.3770	1.3705	1.3619	1.3539	1.3463
0.5	1.3935	1.3885	1.3853	1.3808	1.3749	1.3682	1.3595	1.3514	1.3439
0.6	1.3923	1.3870	1.3836	1.3789	1.3728	1.3659	1.3572	1.3490	1.3414
0.7	1.3912	1.3855	1.3819	1.3770	1.3707	1.3637	1.3549	1.3467	1.3390
0.8	1.3900	1.3841	1.3802	1.3751	1.3686	1.3615	1.3526	1.3444	1.3367

$$c_P = 0.9857 \frac{\left(\frac{\gamma}{\gamma-1}\right)}{1 + O/F}$$

(10)

ENTHALPY OF NORMAL HYDROGEN AT
VARIOUS TEMPERATURES (550 PSIA)

Temp, R	Enthalpy, Btu/lb	Temp, R	Enthalpy, Btu/lb	Temp, R	Enthalpy, Btu/lb
55	- 45	190	480	340	1067
60	- 28	195	498	350	1107
65	- 6	200	517	360	1146
70	18	205	535	370	1185
75	48	210	553	380	1223
80	80	215	572	390	1262
85	103	220	591	400	1300
90	132	225	610	410	1338
95	153	230	629	420	1376
100	174	235	648	430	1413
105	193	240	668	440	1451
110	212	245	688	450	1488
115	230	250	708	460	1525
120	248	255	728	470	1562
125	265	260	747	480	1598
130	282	265	767	500	1670
135	297	270	787	550	1850
140	314	275	808	600	2020
145	330	280	828	650	2200
150	346	285	848	700	2370
155	362	290	868	750	2550
160	378	295	888	800	2720
165	395	300	908	850	2900
170	413	310	948	900	3070
175	430	320	988	950	3240
180	447	330	1028	1000	3420
185	463				

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ENTHALPY (BTU/LB) OF OXYGEN AT 900 PSIA

Temp, R	h, Btu/lb	Δh, Btu/lb-R
140	- 65.2	
		0.40
150	- 61.2	
		0.41
160	- 57.1	
		0.41
170	- 53.0	
		0.40
180	- 49.0	
		0.40
190	- 45.0	
		0.42
200	- 40.8	
		0.41
210	- 36.7	
		0.44
220	- 32.3	
		0.43
230	- 28.0	
		0.48
240	- 23.2	
		0.50
250	- 18.2	
		0.54
260	- 12.8	
		0.61
270	- 6.7	
		0.87
280	2.0	
		2.00
290	22.0	
		1.40
300	36.0	
		0.58
320	47.6	
		0.42
340	56.0	
		0.34
360	62.8	
		0.31
380	69.0	
		0.29
400	74.8	

Temp, R	h, Btu/lb	Δh, Btu/lb-R
400	74.8	
		0.275
420	80.3	
		0.270
440	85.7	
		0.260
460	90.9	
		0.255
480	96.0	
		0.250
500	101	
		0.24
550	113	
		0.24
600	125	
		0.24
650	137	
		0.24
700	149	
		0.24
750	161	
		0.24
800	173	
		0.24
850	185	
		0.24
900	197	
		0.24
950	209	
		0.24
1000	221	

APPENDIX C

DATA REDUCTION FOR SELECTED EVENTS IN ANALYSIS OF APU-T PERFORMANCE

The computer output in this appendix is a compilation of the steady-state APU-T system test data used in the analysis of both component and overall APU performance. Definitions for the test data entitled, Data in Engineering Units, can be found in the section, APU-T System Tests, under the summary of recorded data, table 8. Station number identification can be found in figs. 27, 28, and 29.

The test data has the following units:

Pressure	psig
Temperature	R
Flow	gpm

The calculations listed below the engineering data are based on the equations tabulated in Appendix B.

The test data are shown for runs from power levels of approximately 50 to 380 hp. The events are indicated by the heading, READING, and are listed consecutively starting with reading (event) 131 in run 90 and ending with reading 705 in the last performance test conducted (run 187).

```
                                   RUN 90, EVENT 131
      DATE  10- 4-74            ***   H2O2 APU PERFORMANCE   ***
      TIME  11-11- 2
                                                                         READING    131
                                                                         BAROMETER  13.33 PSIA

      DATA IN ENGINEERING UNITS
RP66   878.72 RP67  556.56 DL68    6.51 DL69    5.70 SP5   875.84 SP7   526.94 DH68    6.89 DH69    5.84
SP18   127.25 SP63    8.20 SP27  553.90 SP58  547.36 SP62   96.95 SP64    0.22 SP66    0.15 LP1  3988.27
LP2    109.00 RT66  502.07 RT67  539.19 ST5   527.18 ST7   629.00 ST16  533.96 ST17  486.26 ST18  579.17
ST19   552.64 ST27  286.34 ST31  386.46 ST35  469.12 ST39  552.35 ST41  476.03 ST45  499.97 ST47 1249.62
ST51   876.66 ST56  307.40 ST57  731.33 ST58  752.30 ST62 1959.18 ST65 1390.42 ST66  824.38 ST84  583.73
ST86   557.42 LT2   535.14 LT5   536.90 LT6   538.84 SN8162598.38 SQ19    7.97 SQ83    0.42 SQ85    0.63
LQ2     17.06 LQ5    71.52

      CALCULATIONS
101     2.444  102     1.504  103     0.615        0.000  104A   47.170  105     5.024  106  9688.035  107     3.256
160     1.370  108     8.137  109  ********  110     3.949  111   174.321  112     9.044  113   311.206  114   119.786
115    54.493  116    50.647  117    68.307  118    31.260  119    29.054  120    18.052         0.000  121B    7.322
        0.000  121D   72.615  121E   11.168  121F   76.461  122    43.325  123    59.099  124     1.228  125     1.216
126     0.624  127     1.820  128     0.169  129     0.964  130     0.498  131     0.460  132     0.756  133     0.241
134     0.413  135     0.823  136     0.841  137     0.635  138    -0.102  139     0.498  140   792.987  141  1211.749
142   652.526  143   628.013  144   685.487  145   880.709  146   199.019  147   185.486  148  3200.153  149  4914.011
150   179.513  151   -36.771  152  8238.153  153  1155.827  154  7082.325  155  1863.231  156  8177.220  157  7858.631
158   104.054  159     3.817  161     0.149

106    9688.                    109 1456428.
145    880.709                  148    3200.153
149    4914.011                 152    8238.153
153    1155.827                 154    7082.325

                                   RUN 90, EVENT 133
      DATE  10- 4-74            ***   H2O2 APU PERFORMANCE   ***
      TIME  11-13-31
                                                                         READING    133
                                                                         BAROMETER  13.33 PSIA

      DATA IN ENGINEERING UNITS
RP66   878.72 RP67  557.22 DL68   13.75 DL69   13.76 SP5   870.23 SP7   508.30 DH68   17.19 DH69   16.02
SP18   123.92 SP63   19.57 SP27  546.42 SP58  530.60 SP62  165.56 SP64    0.35 SP66    0.17 LP1  3950.25
LP2    103.88 RT66  502.38 RT67  540.30 ST5   525.02 ST7   682.58 ST16  544.05 ST17  490.12 ST18  580.52
ST19   544.28 ST27  271.77 ST31  409.40 ST35  468.29 ST39  533.01 ST41  475.84 ST45  495.03 ST47 1303.49
ST51   913.12 ST56  313.97 ST57  725.79 ST58  750.68 ST62 1963.66 ST65 1369.19 ST66  959.90 ST84  600.12
ST86   560.69 LT2   546.03 LT5   536.90 LT6   545.33 SN8162488.13 SQ19    7.26 SQ83    0.44 SQ85    0.70
LQ2     48.94 LQ5    71.42

      CALCULATIONS
101     4.079  102     2.437  103     0.597        0.000  104A  140.452  105     2.784  106  ********  107     3.220
160     1.372  108    13.074  109  ********  110     6.517  111   336.800  112     9.749  113   372.845  114   208.710
115   149.224  116   147.830  117    61.432  118    44.306  119    43.892  120   109.836         0.000  121B    8.772
        0.000  121D   68.258  121E   10.166  121F   69.652  122   139.058  123    53.541  124     2.109  125     1.969
126     1.275  127     2.804  128     0.214  129     0.934  130     0.476  131     0.462  132     0.576  133     0.322
134     0.281  135     0.790  136     0.924  137     0.468  138    -0.123  139     0.784  140  1818.587  141  2611.676
142   816.870  143   766.312  144   091.081  145  1085.855  146   266.182  147   227.211  148  5928.973  149  5935.979
150   355.422  151   -92.166  152  ********  153  5018.887  154  ********  155  1830.698  156  8038.578  157  7829.939
158   102.664  159     4.689  161     0.152

106    15692.                   109 1705370.
145    1085.855                 148    5928.973
149    5935.979                 152   18834.630
153    5018.887                 154   13915.940

                                   RUN 90, EVENT 138
      DATE  10- 4-74            ***   H2O2 APU PERFORMANCE   ***
      TIME  11-16- 1
                                                                         READING    138
                                                                         BAROMETER  13.33 PSIA

      DATA IN ENGINEERING UNITS
RP66   877.52 RP67  557.87 DL68   13.75 DL69   13.76 SP5   865.42 SP7   513.98 DH68   25.49 DH69   23.16
SP18   119.45 SP63   26.86 SP27  542.44 SP58  517.22 SP62  209.17 SP64    0.48 SP66    0.18 LP1  3936.50
LP2     95.50 RT66  504.40 RT67  540.19 ST5   519.49 ST7   695.47 ST16  556.68 ST17  495.50 ST18  584.34
ST19   542.53 ST27  224.17 ST31  411.15 ST35  467.08 ST39  525.31 ST41  474.90 ST45  495.16 ST47 1272.65
ST51   967.86 ST56  314.73 ST57  727.12 ST58  750.17 ST62 1962.70 ST65 1361.14 ST66  997.60 ST84  608.07
ST86   576.86 LT2   551.83 LT5   536.73 LT6   549.16 SN8162456.63 SQ19    6.84 SQ83    0.47 SQ85    0.80
LQ2     66.99 LQ5    71.47

      CALCULATIONS
101     4.880  102     2.945  103     0.603        0.000  104A  183.177  105     2.563  106  ********  107     3.232
160     1.371  108    16.036  109  ********  110     7.825  111   424.830  112    10.833  113   427.146  114   252.632
115   193.227  116   207.097  117    59.314  118    45.483  119    48.748  120   150.132         0.000  121B   10.050
        0.000  121D   69.455  121E    -3.819  121F   55.585  122   197.047  123    50.293  124     2.967  125     1.913
126     1.798  127     3.081  128     0.251  129     0.878  130     0.489  131     0.441  132     0.496  133     0.356
134     0.247  135     0.748  136     0.897  137     0.535  138    -0.111  139     0.847  140  2926.785  141  4022.908
142   928.012  143   830.289  144   959.996  145  1178.101  146   336.182  147   288.578  148  8016.186  149  8033.543
150   393.695  151  -124.388  152  ********  153  7414.519  154  ********  155  1840.566  156  8289.405  157  7837.311
158   105.768  159     5.503  161     0.147

106    18960.                   109 1791562.
145    1178.101                 148    8016.186
149    8033.543                 152   22838.732
153    7414.519                 154   15424.214
```

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RUN 90, EVENT 143

*** H2O2 APU PERFORMANCE ***

```
DATE  10- 4-74                                                                              READING    143
TIME  11-17-45                                                                              BAROMETER  13.33 PSIA

      DATA IN ENGINEERING UNITS
RP66   875.71 RP67   558.69 DL66    13.75 DL69    13.76  SP5   846.38  SP7   504.45 DH68    65.45 DH69    62.09
SP18   133.18 SP63    46.14 SP27   517.22 SP58   456.55 SP62   340.08 SP64     1.08 SP66     0.18  LP1  3840.24
 LP2    86.07 RT66   503.66 RT67   540.71  ST5   516.83  ST7   692.02 ST16   564.93 ST17   500.91 ST18   591.73
ST19   540.13 ST27   178.38 ST31   429.58 ST35   466.50 ST39   509.08 ST41   475.15 ST45   489.82 ST47  1196.99
ST51  1017.78 ST56   360.95 ST57   730.92 ST58   749.77 ST62  1961.42 ST65  1341.70 ST66   834.98 ST84   613.45
ST86   503.84  LT2   561.21  LT5   536.90  LT6   557.19 SN8162377.88 SQ19     6.52 SQ83     0.45 SQ85     0.92
 LQ2   126.65  LQ5    70.52

      CALCULATIONS
 101     7.700  102     4.598  103     0.597            0.000 104A  320.543  105     2.302  106 ********  107     3.219
 160     1.372  108    24.512  109 ********  110    12.299  111   735.008  112    11.661  113   459.865  114   410.372
 115   331.363  116   317.807  117    55.386  118    45.082  119    43.238  120   277.407           0.000 121B    10.820
         0.000 121D    69.829 121E    24.376 121F  103.384  122   306.987  123    47.688  124     5.749  125     1.951
 126     3.363  127     4.337  128     0.282  129     0.801  130     0.464  131     0.426  132     0.340  133     0.412
 134     0.163  135     0.713  136     0.830  137     0.594  138    -0.088  139     0.818  140  5725.641  141  7602.553
 142   966.607  143   804.941  144  1111.290  145  1382.064  146   384.038  147   326.844  148 ********  149 ********
 150   508.109  151  -193.345  152 ********  153 ********  154 ********  155  1829.287  156  8415.066  157  7827.499
 158   107.506  159     6.503  161     0.145

 106   29604.                 109 1972126.
 145    1382.064              148   14114.688
 149   13834.399              152   34526.897
 153   11935.671              154   22591.224
```

RUN 117, EVENT 230

*** H2O2 APU PERFORMANCE ***

```
DATE  11-11-74                                                                              READING    230
TIME  13-28-36                                                                              BAROMETER  13.44 PSIA

      DATA IN ENGINEERING UNITS
RP66   871.90 RP67   553.29 DL68    13.07 DL69    10.10  SP5   867.63  SP7   507.69 DH68    13.32 DH69    10.62
SP18   117.07 SP63    17.06 SP27   547.52 SP58   526.55 SP62   138.46 SP64     0.36 SP66     0.01  LP1  3806.08
 LP2    96.89 RT66   514.28 RT67   537.37  ST5   532.32  ST7   677.73 ST16   561.21 ST17   557.02 ST18   579.90
ST19   571.31 ST27   542.29 ST31   542.34 ST35   553.68 ST39   570.17 ST41   584.66 ST45   557.28 ST47  1388.19
ST51   767.49 ST56   721.86 ST57   763.12 ST58   751.29 ST62  1949.58 ST65  1447.25 ST66  1213.80 ST84   618.38
ST86   588.60  LT2   542.94  LT5   528.70  LT6   543.99 SN8162629.88 SQ19     7.16 SQ83     0.75 SQ85     1.20
 LQ2    34.82  LQ5    29.97

      CALCULATIONS
 101     3.331  102     2.117  103     0.635            0.000 104A  107.030  105     3.054  106 ********  107     3.297
 160     1.369  108    10.997  109 ********  110     5.449  111   261.929  112    16.165  113   309.917  114   144.451
 115   114.322  116   101.572  117    54.947  118    43.646  119    38.778  120    75.363           0.000 121B     7.292
         0.000 121D    37.420 121E    20.042 121F   50.170  122    94.280  123    52.892  124     0.842  125     2.488
 126     0.319  127     3.012  128     0.000  129     0.202  130     0.407  131     0.557  132     0.628  133     0.327
 134     0.399  135     0.639  136     0.933  137     0.262  138     0.051  139     0.630  140     0.647  141    51.012
 142   126.505  143   173.146  144   184.095  145   257.954  146    29.195  147    30.277  148  2442.541  149  2785.725
 150  -137.946  151   -73.902  152 ********  153  3822.838  154 ********  155  1896.757  156  8163.823  157  7883.878
 158   103.550  159     3.282  161     0.149

 106   13633.                 109 1586187.
 145     257.954              148    2442.541
 149    2785.725              152   16225.822
 153    3822.838              154   14402.986
```

RUN 117, EVENT 235

*** H2O2 APU PERFORMANCE ***

```
DATE  11-11-74                                                                              READING    235
TIME  13-30-30                                                                              BAROMETER  13.44 PSIA

      DATA IN ENGINEERING UNITS
RP66   871.30 RP67   554.44 DL68    13.75 DL69    13.76  SP5   859.01  SP7   505.47 DH68    32.23 DH69    23.83
SP18   123.70 SP63    34.08 SP27   541.77 SP58   503.17 SP62   216.47 SP64     0.78 SP66     0.01  LP1  3825.08
 LP2    98.27 RT66   515.55 RT67   534.72  ST5   529.34  ST7   695.57 ST16   575.56 ST17   560.99 ST18   587.76
ST19   573.86 ST27   539.41 ST31   540.53 ST35   552.06 ST39   569.95 ST41   554.08 ST45   561.57 ST47  1394.67
ST51   765.46 ST56   711.80 ST57   761.71 ST58   751.09 ST62  1946.70 ST65  1430.01 ST66  1251.86 ST84   627.16
ST86   596.62  LT2   556.33  LT5   528.70  LT6   555.87 SN8162598.38 SQ19     6.72 SQ83     0.77 SQ85     1.33
 LQ2    71.02  LQ5    29.97

      CALCULATIONS
 101     4.958  102     3.250  103     0.655            0.000 104A  192.716  105     2.555  106 ********  107     3.337
 160     1.367  108    16.149  109 ********  110     8.208  111   433.319  112    17.410  113   364.201  114   221.178
 115   201.285  116   175.409  117    51.051  118    46.451  119    40.480  120   154.432           0.000 121B     8.569
         0.000 121D    28.461 121E    34.445 121F   54.338  122   166.839  123    49.283  124     1.213  125     3.745
 126     0.546  127     4.611  128     0.004  129     0.237  130     0.391  131     0.539  132     0.500  133     0.389
 134     0.348  135     0.678  136     0.959  137     0.205  138     0.045  139     0.715  140    16.622  141    65.119
 142   191.472  143   263.507  144   297.099  145   390.919  146   124.371  147   114.148  148  3526.675  149  3167.423
 150  -184.317  151  -129.668  152 ********  153  6793.593  154 ********  155  1930.539  156  8202.486  157  7909.896
 158   103.699  159     4.119  161     0.146

 106   20924.                 109 1741994.
 145     390.919              148    3526.675
 149    3167.423              152   28954.688
 153    6793.593              154   22161.098
```

RUN 117, EVENT 241

*** H2O2 APU PERFORMANCE ***

```
DATE  11-11-74                                                                READING    241
TIME  13-32-31                                                                BAROMETER  13.44 PSIA

      DATA IN ENGINEERING UNITS
RP66  868.69 RP67  557.54 DL68   13.75 DL69   13.76  SP5  835.16  SP7  498.98 DH68   82.28 DH69   62.20
SP18  114.07 SP63   59.55 SP27  520.78 SP58  443.71 SP62  349.18 SP64    1.64 SP66    0.08  LP1 3595.05
 LP2   70.06 RT66  517.65 RT67  532.54  ST5  525.98  ST7  691.50 ST16  588.26 ST17  562.07 ST18  604.70
ST19  577.42 ST27  537.33 ST31  537.69 ST35  549.11 ST39  567.39 ST41  551.37 ST45  560.99 ST47 1383.72
ST51  763.42 ST56  705.28 ST57  760.09 ST58  750.38 ST62 1946.38 ST65 1408.54 ST66 1220.97 ST84  633.83
ST86  605.42  LT2  575.22  LT5  528.75  LT6  572.90 SN8162535.38 SQ19    5.48 SQ83    0.78 SQ85    1.49
 LQ2  129.52  LQ5   29.97

      CALCULATIONS
101     7.757  102     5.007  103     0.645           0.000 104A  327.556  105     2.338  106 ********  107     3.317
160     1.368  108    24.034  109 ********  110    12.765  111   738.893  112    10.751  113  445.230  114   359.820
115   338.032  116   281.307  117    48.660  118    45.748  119    38.071  120   266.379          0.000 121B    10.475
        0.000 121D    32.264 121E    67.201 121F    88.989  122   270.831  123    39.744  124     1.908  125     5.848
126     0.444  127     7.313  128     0.001  129     0.257  130     0.384  131     0.539  132     0.328  133     0.490
134     0.260  135     0.709  136     0.970  137     0.221  138     0.041  139     0.706  140     9.348  141    90.425
142   296.807  143   416.313  144   475.047  145   625.484  146   250.122  147   222.109  148 5477.648  149 5208.337
150  -263.785  151  -198.912  152 ********  153 ********  154 ********  155 1912.752  156 8319.210  157 7895.145
158   105.371  159     5.585  161     0.144

106    32238.                  109 1910141.
145     625.484                148    5477.648
149    5208.337                152   44792.417
153   11035.271                154   33757.149
```

RUN 118, EVENT 251

*** H2O2 APU PERFORMANCE ***

```
DATE  11-11-74                                                                READING    251
TIME  14-19-19                                                                BAROMETER  13.44 PSIA

      DATA IN ENGINEERING UNITS
RP66  864.08 RP67  545.94 DL68    7.80 DL69    5.72  SP5  865.42  SP7  522.49 DH68    7.80 DH69    6.09
SP18   96.24 SP63    9.73 SP27  540.97 SP58  525.87 SP62  105.96 SP64   -9.85 SP66  -11.31  LP1 3840.08
 LP2   86.32 RT66  518.55 RT67  540.77  ST5  535.41  ST7  665.54 ST16  563.73 ST17  561.04 ST18  585.13
ST19  575.22 ST27  545.55 ST31  546.00 ST35  558.69 ST39  576.46 ST41  559.61 ST45  561.80 ST47 1293.66
ST51  766.48 ST56  723.74 ST57  762.51 ST58  751.19 ST62 1949.26 ST65 1343.71 ST66 1100.97 ST84  620.68
ST86  590.55  LT2  546.49  LT5  530.77  LT6  546.08 SN8162740.13 SQ19    4.81 SQ83    0.77 SQ85    1.22
 LQ2   29.17  LQ5   31.32

      CALCULATIONS
101     2.422  102     1.608  103     0.663           0.000 104A   93.657  105     2.562  106 ********  107     3.354
160     1.366  108    33.269  109 ********  110     4.030  111   246.287  112    16.420  113  302.150  114   126.443
115   100.766  116   104.650  117    51.518  118    40.914  119    42.491  120    63.845          0.000 121B     7.109
        0.000 121D    32.785 121E     3.225 121F    28.901  122    97.541  123    35.472  124     0.677  125     1.745
126     0.224  127     2.198  128     0.002  129     0.193  130     0.416  131     0.553  132     0.672  133     0.374
134     0.531  135     0.652  136     0.935  137     0.310  138     0.049  139     0.572  140     3.663  141    33.604
142   102.968  143   136.789  144   144.247  145   200.467  146    17.794  147    19.788  148 1729.042  149 2098.683
150   -96.045  151   -50.222  152 ********  153 4001.259  154 9471.917  155 1944.824  156 8675.100  157 7920.988
158   109.520  159     3.113  161     0.138

106    10352.                  109 2016279.
145     200.467                148    1729.042
149    2098.683                152   13473.175
153    4001.259                154    9471.917
```

RUN 118, EVENT 255

*** H2O2 APU PERFORMANCE ***

```
DATE  11-11-74                                                                READING    255
TIME  14-21- 0                                                                BAROMETER  13.44 PSIA

      DATA IN ENGINEERING UNITS
RP66  862.07 RP67  544.63 DL68   13.75 DL69   13.76  SP5  855.40  SP7  512.35 DH68   24.06 DH69   17.84
SP18   95.84 SP63   23.61 SP27  535.75 SP58  505.87 SP62  188.66 SP64   -7.85 SP66  -10.00  LP1 3782.09
 LP2   76.23 RT66  518.49 RT67  537.61  ST5  533.87  ST7  691.81 ST16  576.86 ST17  562.70 ST18  588.10
ST19  572.50 ST27  542.17 ST31  543.27 ST35  553.85 ST39  570.51 ST41  555.24 ST45  563.54 ST47 1337.68
ST51  763.93 ST56  712.32 ST57  760.09 ST58  750.17 ST62 1949.58 ST65 1372.54 ST66 1189.14 ST84  628.03
ST86  597.68  LT2  556.45  LT5  530.71  LT6  556.50 SN8162566.88 SQ19    4.72 SQ83    0.78 SQ85    1.34
 LQ2   67.17  LQ5   31.17

      CALCULATIONS
101     4.259  102     2.799  103     0.657           0.000 104A  183.603  105     2.306  106 ********  107     3.340
160     1.367  108    36.154  109 ********  110     7.058  111   438.775  112    17.483  113  360.529  114   211.922
115   192.086  116   171.878  117    48.385  118    43.777  119    39.172  120   145.239          0.000 121B     8.483
        0.000 121D    28.319 121E    20.690 121F    48.527  122   163.395  123    34.639  124     1.102  125     3.157
126     0.316  127     3.942  128     0.004  129     0.232  130     0.388  131     0.560  132     0.486  133     0.455
134     0.383  135     0.654  136     0.956  137     0.226  138     0.043  139     0.698  140    15.682  141    57.248
142   151.017  143   218.008  144   237.760  145   308.106  146   118.448  147   111.460  148 2977.235  149 2793.194
150  -147.866  151  -106.109  152 ********  153 6706.541  154 ********  155 1932.545  156 8385.051  157 7910.194
158   106.003  159     4.063  161     0.143

106    18021.                  109 2051229.
145     308.106                148    2977.235
149    2793.194                152   24742.047
153    6706.541                154   18035.507
```

```
                                    RUN 118, EVENT 260
                              ***   H2O2 APU PERFORMANCE   ***
      DATE  11-11-74                                                                    READING    260
      TIME  14-23-15                                                                    BAROMETER  13.44 PSIA


      DATA IN ENGINEERING UNITS
RP66  861.27 RP67  547.74 DL68   13.75 DL69   13.76  SP5  832.76  SP7  498.78 DH68   77.10 DH69   57.96
SP18  101.88 SP63   50.03 SP27  514.09 SP58  440.20 RP62  333.98 SP64   -3.86 SP66   -6.76  LP1 3628.06
 LP2   58.76 RT66  520.95 RT67  534.08  ST5  529.46  ST7  695.47 ST16  590.61 ST17  563.39 ST18  604.98
ST19  578.04 ST27  538.76 ST31  539.94 ST35  550.73 ST39  568.64 ST41  553.45 ST45  563.31 ST47 1364.72
ST51  761.89 ST56  707.76 ST57  759.08 ST58  749.67 ST62 1943.18 ST65 1384.61 ST66 1192.73 ST84  635.89
ST86  606.86  LT2  575.44  LT5  530.77  LT6  574.60 SN8162551.13 SQ19    5.11 SQ83    0.81 SQ85    1.50
 LQ2  129.67  LQ5   31.27

      CALCULATIONS
 101     7.438  102     4.826  103     0.648          0.000 104A  327.922  105     2.244  106 ********  107     3.324
 160     1.369  108    36.263  109 ********  110     12.264  111   763.252  112    19.027  113  455.976  114   358.088
 115   338.651  116   290.208  117    46.940  118     44.369  119    38.022  120   270.040          0.000 121B    10.728
         0.000 121D    30.165 121E    59.171 121F    78.608  122   279.479  123    37.077  124    1.843  125     5.595
 126     0.386  127     7.052  128     0.005  129      0.242  130     0.375  131     0.529  132    0.330  133     0.496
 134     0.265  135     0.732  136     0.975  137      0.233  138     0.041  139     0.722  140   29.526  141    73.186
 142   268.729  143   378.520  144   446.259  145    576.411  146   245.653  147   234.570  148 5152.579  149  5103.372
 150  -245.117  151  -192.299  152 ********  153  ********  154 ********  155  1917.817  156 8295.681  157  7898.113
 158   105.033  159     5.656  161     0.145

 106    31072.                  109 2053620.
 145     576.411                148    5152.579
 149    5103.372                152   43016.157
 153   11431.622                154   31564.539

                                    RUN 120, EVENT 270
                              ***.  H2O2 APU PERFORMANCE   ***
      DATE  11-25-74                                                                    READING    270
      TIME  13-42- 0                                                                    BAROMETER  13.39 PSIA


      DATA IN ENGINEERING UNITS
RP66  874.11 RP67  551.33 DL68    3.07 DL69    5.13  SP5  882.86  SP7  518.43 DH68    4.97 DH69    5.36
SP18  110.45 SP63    7.69 SP27  552.74 SP58  535.47 SP62   97.65 SP64    0.19 SP66    0.00  LP1 3789.09
 LP2   88.84 RT66  513.62 RT67  544.69  ST5  348.70  ST7  620.89 ST16  533.07 ST17  563.22 ST18  687.30
ST19  668.08 ST27  498.37 ST31  501.65 ST35  583.33 ST39  670.96 ST41  588.65 ST45  554.36 ST47 1353.10
ST51  792.50 ST56  742.20 ST57  788.30 ST58  751.49 ST62 1949.58 ST65 1445.01 ST66 1110.04 ST84  603.32
ST86  579.51  LT2  642.80  LT5  530.95  LT6  535.02 SN8162692.88 SQ19   10.43 SQ83    0.77 SQ85    1.17
 LQ2   18.77  LQ5   -0.12

      CALCULATIONS
 101     2.296  102     1.012  103     0.440          0.000 104A   52.242  105     3.800  106 6519.535  107     2.905
 160     1.383  108     8.171  109 ********  110      3.309  111   160.925  112    15.985  113  184.421  114    99.179
 115    56.581  116    20.522  117    60.392  118     35.160  119    12.752  120    22.521          0.000 121B     4.339
         0.000 121D    46.936 121E    40.398 121F    82.995  122    16.183  123    72.804  124    0.684  125     1.611
 126     0.191  127     2.104  128     0.011  129      0.171  130     0.482  131     0.486  132    0.842  133     0.184
 134     0.616  135     0.542  136     0.896  137      0.376  138     0.083  139     0.619  140   25.414  141    33.755
 142   628.421  143   651.097  144   692.039  145    879.891  146  -263.798  147  -213.480  148 1906.600  149  2732.057
 150  -295.852  151   -71.953  152 8989.608  153     -4.245  154 8993.854  155  1563.327  156 9828.098  157  7594.065
 158   129.418  159     1.650  161     0.130

 106     6519.                  109 1604838.
 145     879.891                148    1906.600
 149    2732.057                152    8989.608
 153      -4.245                154    8993.854

                                    RUN 120, EVENT 276
                              ***   H2O2 APU PERFORMANCE   ***
      DATE  11-25-74                                                                    READING    276
      TIME  13-43-45                                                                    BAROMETER  13.39 PSIA


      DATA IN ENGINEERING UNITS
RP66  871.90 RP67  551.66 DL68   13.75 DL69   13.39  SP5  911.51  SP7  500.40 DH68   17.67 DH69   13.82
SP18  122.38 SP63   21.11 SP27  546.99 SP58  521.82 SP62  164.66 SP64    0.48 SP66    0.00  LP1 3787.09
 LP2   99.57 RT66  516.21 RT67  537.61  ST5  331.12  ST7  652.61 ST16  550.85 ST17  541.30 ST18  704.97
ST19  659.12 ST27  375.25 ST31  380.39 ST35  511.99 ST39  648.07 ST41  526.74 ST45  536.72 ST47 1391.09
ST51  793.51 ST56  730.17 ST57  789.20 ST58  750.17 ST62 1948.94 ST65 1438.74 ST66 1202.37 ST84  615.76
ST86  586.58  LT2  675.21  LT5  529.88  LT6  533.43 SN8162903.88 SQ19   10.43 SQ83    0.69 SQ85    1.08
 LQ2   41.62  LQ5   -0.12

      CALCULATIONS
 101     3.755  102     2.427  103     0.641          0.000 104A  123.126  105     3.027  106 ********  107     3.308
 160     1.368  108    12.828  109 ********  110      6.213  111   311.246  112    14.774  113  368.445  114   166.689
 115   131.795  116    49.658  117    53.424  118     42.344  119    15.954  120    89.552          0.000 121B     8.669
         0.000 121D    43.563 121E    90.806 121F   125.700  122    40.989  123    71.451  124    1.137  125     2.647
 126     0.257  127     3.528  128     0.012  129      0.151  130     0.491  131     0.453  132    0.705  133     0.237
 134     0.414  135     0.395  136     0.947  137      0.262  138     0.085  139     0.701  140   63.408  141    57.039
 142  1681.088  143  1558.744  144  1745.756  145   2069.200  146   126.619  147    62.376  148 3386.796  149  3203.819
 150  -517.050  151  -207.208  152 ********  153     -3.697  154 ********  155  1905.378  156 8392.799  157  7889.107
 158   106.384  159     4.204  161     0.143

 106    15629.                  109 1653153.
 145    2069.200                148    3386.796
 149    3203.819                152   16201.547
 153      -3.697                154   16205.248
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                                   RUN 122, EVENT 308
                           ***     H2O2 APU PERFORMANCE     ***
      DATE  11-26-74
      TIME  15-32-26                                                                READING    308
                                                                                    BAROMETER  13.38 PSIA

      DATA IN ENGINEERING UNITS
RP66  872.50 RP67  556.24 DL68  -13.75 DL69  -13.76  SP5  831.56  SP7  490.88 DH68    84.41 DH69    64.64
SP18  118.76 SP63   55.99 SP27  511.82 SP58  441.41 SP62  347.78 SP64    1.51 SP66     0.04  LP1 3656.07
 LP2   81.36 RT66  513.20 RT67  531.01  ST5  321.97  ST7  503.42 ST16  577.53 ST17   538.19 ST18  703.39
ST19  622.31 ST27  213.53 ST31  386.33 ST35  467.84 ST39  562.99 ST41  487.14 ST45   503.54 ST47 1316.23
ST51  964.59 ST56  325.47 ST57  748.04 ST58  750.88 ST62 1942.22 ST65 1406.30 ST66  988.14 ST84  619.42
ST86  595.18  LT2  675.69  LT5  529.58  LT6  584.51 SN8162472.38 SQ19    9.10 SQ83     0.54 SQ85    1.00
 LQ2  129.37  LQ5   15.72

      CALCULATIONS
 101    7.888  102     5.098  103     0.646          0.000 104A  327.189  105     2.361  106 ********  107     3.319
 160    1.368  108    24.247  109 ********  110     12.986  111  751.343  112    12.864  113  369.304  114   364.489
 115  335.879  116   237.640  117    48.493  118    44.703  119   31.620  120   269.823         0.000 121B     8.689
        0.000 121D    37.299 121E   106.927 121F   135.537  122  228.951  123    62.330  124    4.475  125     3.413
 126    2.672  127     5.215  128     0.230  129     0.850  130    0.461  131     0.429  132    0.403  133     0.344
 134    0.181  135     0.435  136     0.900  137     0.463  138   -0.006  139     0.425  140 4341.322  141  5853.250
 142 2171.260  143  2009.580  144  2526.982  145  3133.456  146  438.585  147   225.896  148 ********  149 ********
 150   78.436  151  -270.286  152 ********  153  7203.457  154 ********  155  1914.734  156 8144.197  157  7897.382
 158  103.125  159     4.907  161     0.147

 106    32824.                 109 1909172.
 145    3133.456               148   12646.429
 149   11760.102               152   34765.149
 153    7203.457               154   27561.696
// END    28 FEB 75 14.431 HRS
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                                   RUN 131, EVENT 315
                           ***     H2O2 APU PERFORMANCE     ***
      DATE  12- 4-74
      TIME  14-16-30                                                                READING    315
                                                                                    BAROMETER  13.26 PSIA

      DATA IN ENGINEERING UNITS
RP66  879.33 RP67  558.20 DL68    4.07 DL69    3.08  SP5  882.46  SP7  519.85 DH68     3.89 DH69     3.29
SP18   89.11 SP63    2.51 SP27  558.63 SP58  538.85 SP62   73.75 SP64  -10.05 SP66   -11.10  LP1 3826.08
 LP2   75.99 RT66  486.20 RT67  517.41  ST5  513.92  ST7  588.45 ST16  533.25 ST17   548.24 ST18  679.19
ST19  657.25 ST27  463.35 ST31  466.50 ST35  562.99 ST39  661.63 ST41  567.61 ST45   543.93 ST47 1193.62
ST51  770.04 ST56  731.26 ST57  766.24 ST58  752.30 ST62 1955.34 ST65 1293.88 ST66  932.59 ST84  590.33
ST86  567.16  LT2  624.82  LT5  525.49  LT6  527.21 SN8162755.88 SQ19    8.72 SQ83     0.71 SQ85    1.05
 LQ2   13.97  LQ5   15.72

      CALCULATIONS
 101    1.832  102     1.205  103     0.658          0.000 104A   48.709  105     3.742  106 7764.061  107     3.342
 160    1.367  108    27.118  109 ********  110      3.038  111  179.798  112    14.623  113  182.938  114   104.338
 115   53.013  116    24.164  117    58.232  118    29.485  119   13.439  120    19.081         0.000 121B     4.304
        0.000 121D    55.629 121E    33.153 121F    84.478  122   19.869  123    61.490  124    0.637  125     1.194
 126    0.179  127     1.653  128     0.010  129     0.126  130    0.494  131     0.481  132    0.848  133     0.188
 134    0.689  135     0.436  136     0.866  137     0.481  138    0.055  139     0.295  140   19.568  141    24.312
 142  595.356  143   569.501  144   617.882  145   841.196  146 -145.355  147   -96.520  148 1442.063  149  2352.569
 150  -89.399  151   -21.573  152  6258.571  153   226.176  154 6032.395  155  1936.444  156 8387.576  157  7916.099
 158  105.955  159     1.718  161     0.143

 106     7764.                 109 1952896.
 145     841.196               148    1442.063
 149    2352.569               152    6258.571
 153     226.176               154    6032.395
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                                   RUN 136, EVENT 336
                           ***     H2O2 APU PERFORMANCE     ***
      DATE  12- 6-74
      TIME  14-57-30                                                                READING    336
                                                                                    BAROMETER  13.46 PSIA

      DATA IN ENGINEERING UNITS
RP66  883.34 RP67  557.54 DL68    3.86 DL69    3.13  SP5  881.45  SP7  520.06 DH68     4.02 DH69     3.04
SP18   83.43 SP63    2.15 SP27  582.34 SP58  558.98 SP62   76.15 SP64  -10.36 SP66   -11.54  LP1 3805.08
 LP2   76.11 RT66  493.09 RT67  533.43  ST5  520.93  ST7  633.36 ST16  544.45 ST17   545.74 ST18  688.57
ST19  653.76 ST27  417.28 ST31  421.28 ST35  543.05 ST39  661.84 ST41  548.47 ST45   545.35 ST47 1253.20
ST51  764.70 ST56  732.41 ST57  762.41 ST58  748.65 ST62 1964.62 ST65 1319.36 ST66 1035.96 ST84  603.93
ST86  577.93  LT2  609.44  LT5  525.90  LT6  526.20 SN8162771.63 SQ19    6.39 SQ83     0.71 SQ85    1.04
 LQ2   13.97  LQ5   13.07

      CALCULATIONS
 101    1.818  102     1.167  103     0.642          0.000 104A   43.909  105     4.061  106 7519.049  107     3.310
 160    1.368  108    20.869  109 ********  110      2.986  111  180.839  112    14.569  113  274.843  114   101.065
 115   50.376  116    24.550  117    55.882  118    27.856  119   13.575  120    13.916         0.000 121B     6.466
        0.000 121D    57.155 121E    32.292 121F    82.981  122   18.083  123    45.494  124    0.563  125     1.255
 126    0.128  127     1.690  128     0.011  129     0.092  130    0.506  131     0.471  132    0.816  133     0.239
 134    0.777  135     0.319  136     0.914  137     0.366  138    0.056  139     0.465  140   24.704  141    14.528
 142  749.093  143   703.122  144   736.111  145   989.699  146  -19.025  147    -8.253  148 1389.379  149  1834.979
 150  -87.596  151   -31.513  152  6704.090  153    32.439  154 6671.650  155  1905.350  156 8788.177  157  7886.994
 158  111.426  159     2.895  161     0.137

 106     7519.                 109 1998158.
 145     989.699               148    1389.379
 149    1834.979               152    6704.090
 153      32.439               154    6671.650
// END    28 FEB 75 13.984 HRS
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RUN 144, EVENT 374

*** H2O2 APU PERFORMANCE ***

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 DATE  12-16-74                                                                READING   374
 TIME  13-42-30                                                                BAROMETER  13.42 PSIA

       DATA IN ENGINEERING UNITS
RP66   872.30 RP67   557.71 DL68     5.87 DL69     4.31  SP5   872.24  SP7   520.06 DH68     5.84 DH69     4.42
SP18   115.83 SP63     5.91 SP27   551.14 SP58   538.58 SP62    93.85 SP64    -9.68 SP66   -10.90  LP1 3764.08
 LP2    81.84 RT66   501.77 RT67   532.07  ST5   525.39  ST7   648.74 ST16   549.11 ST17   551.54 ST18   694.54
ST19   672.87 ST27   413.70 ST31   419.72 ST35   547.71 ST39   676.28 ST41   555.29 ST45   550.98 ST47 1273.10
ST51   765.46 ST56   718.41 ST57   762.11 ST58   749.67 ST62 1954.38 ST65 1331.87 ST66 1080.53 ST84   609.50
ST86   583.56  LT2   646.52  LT5   526.20  LT6   526.91 SN8162645.63 SQ19    10.43 SQ83     0.74 SQ85     1.11
 LQ2    22.17  LQ5    14.77

       CALCULATIONS
101      2.140  102      1.424  103      0.665          0.000 104A    52.242  105      4.094  106 9169.316  107      3.357
160      1.366  108     28.668  109 ********  110      3.565  111   212.442  112     15.368  113  288.485  114   114.861
115     59.030  116     30.974  117     54.269  118     27.786  119    14.580  120     47.639           0.000 121B     6.787
         0.000 121D     62.618 121E     34.844 121F     90.674  122    24.186  123     72.649  124      0.635  125      1.504
126      0.152  127      1.988  128      0.017  129      0.133  130     0.498  131      0.471  132      0.875  133      0.147
134      0.697  135      0.393  136      0.924  137      0.321  138     0.052  139      0.521  140     43.762  141     25.091
142    926.567  143    885.630  144    940.003  145    995.593  146   -30.965  147    -16.597  148 1599.915  149 1919.087
150    -93.242  151    -42.164  152  8296.917  153     87.920  154  8208.998  155   1945.937  156 8812.535  157 7919.768
158    111.272  159      3.089  161      0.136

106      9169.                 109 1966438.
145      995.593               148    1599.915
149     1919.067               152    8296.917
153       87.920               154    8208.998
```

RUN 144, EVENT 378

*** H2O2 APU PERFORMANCE ***

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 DATE  12-16-74                                                                READING   378
 TIME  13-45- 0                                                                BAROMETER  13.42 PSIA

       DATA IN ENGINEERING UNITS
RP66   870.70 RP67   550.89 DL66    10.22 DL69     7.71  SP5   868.63  SP7   501.62 DH68    10.23 DH69     8.27
SP18   120.44 SP63    12.05 SP27   547.79 SP58   533.98 SP62   127.96 SP64    -9.13 SP66   -10.93  LP1 3767.08
 LP2    90.06 RT66   501.52 RT67   530.24  ST5   525.02  ST7   688.04 ST16   568.55 ST17   550.38 ST18   715.21
ST19   676.33 ST27   317.97 ST31   305.87 ST35   493.28 ST39   673.72 ST41   508.35 ST45   536.48 ST47 1315.56
ST51   765.46 ST56   713.53 ST57   761.00 ST58   748.86 ST62 1955.02 ST65 1362.03 ST66 1131.52 ST84   619.42
ST86   591.67  LT2   675.64  LT5   526.08  LT6   526.80 SN8162590.38 SQ19    10.43 SQ83     0.67 SQ85     1.04
 LQ2    29.72  LQ5    14.22

       CALCULATIONS
101      2.870  102      1.660  103      0.655          0.000 104A    94.959  105      3.001  106 ********  107      3.336
160      1.367  108     32.950  109 ********  110      4.750  111   291.620  112     14.158  113  327.037  114   146.726
115    102.654  116     51.079  117     50.388  118     35.201  119    17.515  120     63.768           0.000 121B     7.694
         0.000 121D     51.766 121E     59.269 121F    103.341  122    43.384  123     71.434  124      0.843  125      2.026
126      0.246  127      2.623  128     -0.027  129      0.116  130     0.509  131      0.449  132      0.813  133      0.175
134      0.468  135      0.299  136      0.943  137      0.279  138     0.051  139      0.690  140 -113.180  141     44.788
142   1790.979  143   1613.308  144   1759.197  145   1777.164  146   270.469  147    113.703  148 2288.749  149 2362.473
150   -122.007  151    -73.571  152 ********  153     84.647  154 ********  155   1927.870  156 8715.712  157 7904.787
158    110.258  159      3.699  161      0.138

106     12106.                 109 2025736.
145     1777.164               148    2289.749
149     2362.473               152   11625.155
153       84.647               154   11540.507
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RUN 144, EVENT 386

*** H2O2 APU PERFORMANCE ***

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 DATE  12-16-74                                                                READING   386
 TIME  13-49-31                                                                BAROMETER  13.42 PSIA

       DATA IN ENGINEERING UNITS
RP66   868.89 RP67   559.01 DL68    13.75 DL69    13.76  SP5   857.01  SP7   497.36 DH68    32.49 DH69    24.34
SP18   118.94 SP63    30.38 SP27   540.30 SP58   511.82 SP62   227.67 SP64    -6.83 SP66    -9.04  LP1 3708.08
 LP2    82.98 RT66   500.91 RT67   527.92  ST5   517.19  ST7   700.26 ST16   590.83 ST17   547.36 ST18   738.19
ST19   675.05 ST27   224.49 ST31   311.36 ST35   466.38 ST39   644.15 ST41   491.48 ST45   519.73 ST47 1356.00
ST51   844.07 ST56   284.04 ST57   730.10 ST58   747.33 ST62 1957.90 ST65 1394.67 ST66 1091.21 ST84   626.56
ST86   601.22  LT2   705.18  LT5   526.32  LT6   554.31 SN8162488.13 SQ19    10.43 SQ83     0.63 SQ85     1.07
 LQ2    71.67  LQ5    14.37

       CALCULATIONS
101      5.062  102      3.305  103      0.652          0.000 104A   194.254  105      2.584  106 ********  107      3.332
160      1.367  108     36.604  109 ********  110      8.368  111   524.201  112     14.081  113  393.151  114   246.028
115    203.505  116    159.942  117     46.945  118     38.822  119    30.511  120    151.592           0.000 121B     9.250
         0.000 121D     51.773 121E     52.813 121F     95.336  122   150.691  123     70.201  124      1.963  125      3.099
126      1.030  127      4.032  128      0.140  129      0.903  130     0.465  131      0.458  132      0.654  133      0.232
134      0.285  135      0.434  136      0.955  137      0.346  138    -0.080  139      0.859  140 1376.382  141 1958.561
142   2605.608  143   2616.015  144   3048.249  145   2865.156  146   481.187  147    272.336  148 5715.872  149 5486.242
150    305.411  151   -145.226  152 ********  153   3356.135  154 ********  155   1922.313  156 8437.275  157 7898.404
158    106.822  159      4.957  161      0.143

106     21279.                 109 2067181.
145     2865.156               148    5715.872
149     5486.242               152   22961.141
153     3356.135               154   19605.007
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                                   RUN 144, EVENT 394
DATE  12-16-74                *** H202 APU PERFORMANCE ***
TIME  13-53-33
                                                                            READING     394
                                                                            BAROMETER   13.42 PSIA

     DATA IN ENGINEERING UNITS
RP66  866.69 RP67  562.12 DL68   13.75 DL69   13.76  SP5  834.76  SP7  484.39 DH68   80.32 DH69   59.26
SP18  102.87 SP63   53.71 SP27  520.24 SP58  458.17 SP62  360.28 SP64   -3.74 SP66   -6.74  LP1 3575.04
 LP2   60.50 RT66  500.24 RT67  525.90  ST5  514.77  ST7  691.91 ST16  601.96 ST17  556.33 ST18  743.91
ST19  666.27 ST27  196.06 ST31  345.54 ST35  465.48 ST39  606.36 ST41  493.40 ST45  516.10 ST47 1341.70
ST51  909.55 ST56  291.82 ST57  719.42 ST58  746.11 ST62 1957.90 ST65 1401.83 ST66 1047.89 ST84  633.51
ST86  609.77  LT2  713.90  LT5  526.62  LT6  582.77 SN8162377.88 SQ19   10.43 SQ83    0.67 SQ85    1.21
 LQ2  130.37  LQ5   14.02

     CALCULATIONS
 101     7.677  102     5.033  103     0.655            0.000 104A   329.631  105     2.313  106 ********  107     3.337
 160     1.367  108    38.617  109 ********  110    12.710  111   802.314  112    15.560  113   428.058  114   368.444
 115   339.703  116   250.313  117    45.945  118    42.340  119    31.198  120   267.332            0.000 121B    10.071
         0.000 121D    38.812 121E    99.462 121F   128.203  122   240.241  123    69.857  124     3.658  125     4.018
 126     2.363  127     5.314  128     0.209  129     0.865  130     0.459  131     0.433  132     0.505  133     0.278
 134     0.209  135     0.418  136     0.932  137     0.399  138    -0.130  139     0.865  140  3638.313  141  4976.261
 142  3072.287  143  2913.075  144  3641.979  145  3499.822  146   586.284  147   319.185  148 ********  149  9699.169
 150   717.375  151  -213.990  152 ********  153  6568.289  154 ********  155  1925.796  156  8610.141  157  7899.440
 158   108.996  159     5.595  161     0.140

 106    32404.                     109 2083003.
 145    3499.822                   148   10511.667
 149    9699.169                   152   35078.606
 153    6568.289                   154   28510.318
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                                   RUN 145, EVENT 400
DATE  12-17-74                *** H202 APU PERFORMANCE ***
TIME  15-56-21
                                                                            READING     400
                                                                            BAROMETER   13.34 PSIA

     DATA IN ENGINEERING UNITS
RP66  881.93 RP67  553.46 DL68    6.16 DL69    4.73  SP5  880.6   SP7  517.02 DH68    6.02 DH69    4.65
SP18  103.60 SP63    6.96 SP27  548.19 SP58  535.74 SP62   96.75 SP64   -9.53 SP66  -11.00  LP1 3760.08
 LP2   72.66 RT66  501.40 RT67  525.07  ST5  521.18  ST7  602.72 ST16  591.54 ST17  545.15 ST18  694.75
ST19  676.49 ST27  421.41 ST31  423.04 ST35  551.54 ST39  682.27 ST41  559.03 ST45  542.64 ST47 1197.66
ST51  765.46 ST56  723.48 ST57  763.62 ST58  750.17 ST62 1960.14 ST65 1297.01 ST66  958.26 ST84  591.33
ST86  568.07  LT2  648.29  LT5  865.60  LT6  529.41 SN8162677. 3 SQ19   24.99 SQ83    0.69 SQ85    1.04
 LQ2   22.47  LQ5   14.17

     CALCULATIONS
 101     2.250  102     1.467  103     0.651            0.000 104A    77.798  105     2.867  106  9446.393  107     3.330
 160     1.367  108    28.877  109 ********  110     3.717  111   223.718  112    14.426  113   205.394  114   128.488
 115    82.631  116  -906.660  117    57.559  118    36.935  119  -405.267  120    48.391            0.000 121B     4.832
         0.000 121D    50.690 121E   994.124 121F  1039.982  122  -911.493  123   173.903  124     0.765  125     1.484
 126     0.098  127     2.152  128     0.004  129     0.122  130     0.495  131     0.475  132     0.912  133     0.127
 134     0.596  135     0.495  136     0.868  137     0.449  138     0.055  139     0.336  140    12.469  141    14.459
 142   977.463  143   949.493  144  1005.998  145  2012.560  146  -123.636  147   -86.358  148  1745.541  149  2710.240
 150  -105.943  151   -28.714  152 ********  153 ********  154  7619.061  155  1923.637  156  8672.742  157  7905.318
 158   109.735  159     2.055  161     0.139

 106     9446.                     109 1985742.
 145    2012.560                   148    1745.541
 149    2710.240                   152  -32125.421
 153  -39744.488                   154    7619.061
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                                   RUN 145, EVENT 406
DATE  12-17-74                *** H202 APU PERFORMANCE ***
TIME  15-59-11
                                                                            READING     406
                                                                            BAROMETER   13.34 PSIA

     DATA IN ENGINEERING UNITS
RP66  877.92 RP67  552.97 DL68   10.44 DL69    8.08  SP5  873.64  SP7  503.84 DH68   10.71 DH69    8.27
SP18  108.14 SP63   13.04 SP27  546.05 SP58  530.33 SP62  131.06 SP64   -9.02 SP66  -11.10  LP1 3727.08
 LP2   70.58 RT66  499.87 RT67  527.27  ST5  521.90  ST7  679.63 ST16  553.97 ST17  537.43 ST18  722.33
ST19  683.75 ST27  315.44 ST31  335.83 ST35  495.32 ST39  684.65 ST41  510.60 ST45  530.17 ST47 1306.40
ST51  762.66 ST56  714.21 ST57  754.99 ST58  748.35 ST62 1959.50 ST65 1354.88 ST66 1119.09 ST84  610.87
ST86  583.61  LT2  684.18  LT5  865.60  LT6  527.33 SN8162519.63 SQ19   24.99 SQ83    0.63 SQ85    0.95
 LQ2   29.42  LQ5   14.02

     CALCULATIONS
 101     2.933  102     1.934  103     0.659            0.000 104A    94.249  105     3.099  106 ********  107     3.345
 160     1.367  108    33.418  109 ********  110     4.868  111   299.662  112    13.214  113   330.320  114   152.964
 115   102.021  116  -878.766  117    51.153  118    34.045  119  -293.252  120    62.772            0.000 121B     7.772
         0.000 121D    58.715 121E   980.560 121F  1039.503  122  -886.538  123   170.314  124     0.878  125     2.055
 126     0.161  127     2.772  128     0.045  129     0.108  130     0.457  131     0.498  132     0.834  133     0.169
 134     0.451  135     0.381  136     0.941  137     0.285  138     0.048  139     0.662  140   195.021  141    27.385
 142  1564.561  143  1738.062  144  1888.920  145  4233.040  146   192.413  147    96.627  148  2374.610  149  2469.723
 150  -119.564  151   -73.244  152 ********  153 ********  154 ********  155  1934.706  156  8685.875  157  7909.366
 158   109.817  159     3.788  161     0.138

 106    12456.                     109 2031065.
 145    4233.040                   148    2374.610
 149    2469.723                   152  -27902.562
 153  -39566.834                   154   11664.261
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                                   RUN 145, EVENT 412
                              ***    H202 APU PERFORMANCE    ***
      DATE  12-17-74                                                                       READING     412
      TIME  16- 3-11                                                                       BAROMETER  13.34 PSIA


      DATA IN ENGINEERING UNITS
RP66  873.31 RP67  556.89 DL68   13.75 DL69   13.76  SP5  861.82  SP7  504.05 DH68   31.45 DH69   24.26
SP18  110.74 SP63   31.13 SP27  536.82 SP58  506.68 SP62  235.97 SP64   -6.78 SP66   -9.38  LP1 3683.07
 LP2   79.69 RT66  499.56 RT67  526.08  ST5  514.89  ST7  698.08 ST16  576.35 ST17  540.07 ST18  650.65
ST19  669.89 ST27  218.58 ST31  313.55 ST35  467.40 ST39  654.14 ST41  492.10 ST45  516.10 ST47 1352.43
ST51  840.88 ST56  284.04 ST57  731.43 ST58  747.94 ST62 1956.94 ST65 1390.42 ST66 1082.12 ST84  619.47
ST86  594.84  LT2  713.85  LT5  865.60  LT6  547.36 SN8162488.13 SQ19   24.99 SQ83    0.58 SQ85    0.98
 LQ2   70.52  LQ5   14.12

      CALCULATIONS
 101     5.053  102     3.266  103     0.646            0.000 104A  191.532  105     2.606  106 ********  107     3.319
 160     1.368  108    38.003  109 ********  110     8.319  111  525.624  112    13.105  113  367.996  114   246.882
 115   200.191  116  -798.150  117    46.940  118    38.086  119 -151.848  120   148.266           0.000 121B    8.658
         0.000 121D    55.350 121E 1007.000 121F 1053.692  122 -806.809  123   167.348  124     1.962  125     3.090
 126     0.993  127     4.059  128     0.152  129     0.894  130    0.451  131     0.475  132     1.019  133    -0.105
 134     0.284  135     0.430  136     0.956  137     0.352  138   -0.076  139     0.845  140 1502.785  141  1876.927
 142  2581.941  143  2774.983  144  3199.459  145 ********  146  408.199  147   212.264  148 5711.436  149  5560.432
 150   292.054  151  -143.618  152 ********  153 ********  154 ********  155  1911.994  156 8775.877  157  7891.210
 158   111.210  159     4.647  161     0.137

 106    21030.                  109 2084875.
 145  -1991.606                 148    5711.436
 149   5560.432                 152 -18094.523
 153 -37488.873                 154  19394.346

                                   RUN 147, EVENT 420
                              ***    H202 APU PERFORMANCE    ***
      DATE  12-18-74                                                                       READING     420
      TIME  15-23- 0                                                                       BAROMETER  13.33 PSIA


      DATA IN ENGINEERING UNITS
RP66  867.09 RP67  549.86 DL68    5.97 DL69    4.48  SP5  871.43  SP7  526.34 DH68    6.23 DH69    4.88
SP18  118.90 SP63    5.40 SP27  550.47 SP58  536.41 SP62   95.85 SP64   -9.58 SP66  -10.88  LP1 3775.09
 LP2   89.45 RT66  502.38 RT67  536.26  ST5  522.62  ST7  650.57 ST16  553.74 ST17  542.06 ST18  689.10
ST19  663.39 ST27  353.24 ST31  357.96 ST35  510.23 ST39  670.16 ST41  520.11 ST45  538.50 ST47 1315.56
ST51  763.93 ST56  715.73 ST57  761.10 ST58  747.74 ST62 1955.66 ST65 1356.67 ST66 1119.09 ST84  604.04
ST86  579.00  LT2  639.89  LT5  865.60  LT6  526.91 SN8162692.88 SQ19   13.62 SQ83    0.65 SQ85    0.96
 LQ2   14.97  LQ5   15.17

      CALCULATIONS
 101     2.159  102     1.430  103     0.662            0.000 104A   58.850  105     3.661  106 9208.348  107     3.351
 160     1.367  108    29.077  109 ********  110     3.589  111  214.876  112    13.435  113  278.620  114   111.540
 115    65.386  116  -974.388  117    52.047  118    30.429  119 -453.463  120    29.292           0.000 121B    6.555
         0.000 121D    52.709 121E 1046.330 121F 1092.484  122 -980.944  123    95.227  124     0.626  125     1.533
 126     0.126  127     2.032  128     0.011  129     0.117  130    0.487  131     0.480  132     0.894  133     0.143
 134     0.546  135     0.347  136     0.944  137     0.290  138    0.056  139     0.536  140   33.219  141    21.391
 142  1104.259  143  1162.184  144  1173.654  145 1537.502  146  133.014  147    69.484  148 1695.624  149  1831.882
 150  -101.004  151   -43.921  152 ********  153 ********  154 8586.277  155  1938.967  156 8908.202  157  7911.807
 158   112.593  159     3.048  161     0.138

 106     9208.                  109 1975277.
 145   1537.502                 148    1695.624
 149   1831.882                 152 -34277.519
 153 -42063.803                 154    8586.277

                                   RUN 147, EVENT 424
                              ***    H202 APU PERFORMANCE    ***
      DATE  12-18-74                                                                       READING     424
      TIME  15-25- 0                                                                       BAROMETER  13.33 PSIA


      DATA IN ENGINEERING UNITS
RP66  865.48 RP67  559.99 DL68   13.75 DL69   13.76  SP5  852.20  SP7  501.01 DH68   43.63 DH69   32.01
SP18  123.33 SP63   37.60 SP27  540.57 SP58  500.47 SP62  262.47 SP64   -5.90 SP66   -8.63  LP1 3704.08
 LP2   80.50 RT66  505.13 RT67  529.53  ST5  520.69  ST7  695.15 ST16  563.79 ST17  531.42 ST18  731.84
ST19  664.67 ST27  223.19 ST31  332.12 ST35  467.72 ST39  629.44 ST41  492.41 ST45  509.29 ST47 1341.03
ST51  870.37 ST56  284.04 ST57  726.30 ST58  747.74 ST62 1956.62 ST65 1388.63 ST66 1045.82 ST84  615.04
ST86  588.15  LT2  704.81  LT5  865.60  LT6  526.68 SN8162440.88 SQ19   13.45 SQ83    0.53 SQ85    0.92
 LQ2   88.92  LQ5   15.17

      CALCULATIONS
 101     5.764  102     3.778  103     0.655            0.000 104A  228.410  105     2.506  106 ********  107     3.337
 160     1.367  108    37.116  109 ********  110     9.543  111  598.175  112    12.190  113  353.964  114   282.479
 115   236.739  116  -926.792  117    47.263  118    39.576  119 -154.936  120   187.996           0.000 121B    8.328
         0.000 121D    54.068 121E 1171.860 121F 1217.600  122 -935.121  123    90.545  124     2.502  125     3.262
 126     1.416  127     4.348  128     0.168  129     0.905  130    0.456  131     0.460  132     0.612  133     0.254
 134     0.236  135     0.453  136     0.945  137     0.389  138   -0.104  139     0.848  140 1980.630  141  2823.017
 142  2603.017  143  2667.148  144  3151.227  145 3900.437  146  328.142  147   174.740  148 7241.485  149  7051.360
 150   432.484  151  -158.222  152 ********  153 ********  154 ********  155  1927.266  156 8463.482  157  7902.795
 158   107.094  159     4.496  161     0.142

 106    24328.                  109 2068362.
 145   3900.437                 148    7241.485
 149   7051.360                 152 -21529.696
 153 -42893.897                 154  21364.196
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                                    RUN 147, EVENT 432
                              ***    H2O2 APU PERFORMANCE    ***
      DATE  12-18-74
      TIME  15-29- 1                                                              READING    432
                                                                                  BAROMETER  13.33 PSIA


      DATA IN ENGINEERING UNITS
RP66  866.69 RP67  559.50 DL68    11.91 DL69    8.99  SP5   870.23  SP7   511.34 DH68    11.93 DH69     8.98
SP18  112.17 SP63    13.80 SP27  556.22 SP58  542.22 SP62   141.86 SP64    -8.85 SP66   -10.85  LP1 3699.08
 LP2   77.62 RT66  506.53 RT67  529.82  ST5   519.49  ST7   697.87 ST16   584.06 ST17   545.50 ST18   772.80
ST19  718.93 ST27  227.07 ST31  234.42 ST35  465.61 ST39   717.88 ST41   488.19 ST45   528.14 ST47 1332.54
ST51  767.24 ST56  505.92 ST57  755.54 ST58  746.01 ST62 1954.06 ST65 1374.10 ST66 1144.15 ST84   625.96
ST86  599.23  LT2  733.56  LT5  865.60  LT6  525.25 SN8162519.63 SO19    13.76 SO83     0.62 SO85     0.99
 LQ2   31.62  LQ5   15.32

      CALCULATIONS
 101    3.106  102    2.014  103    0.648          0.000 104A   99.456  105     5.069  106 ********  107     3.323
 160    1.368  108   34.630  109 ********  110     5.121  111  317.859  112    13.389  113  377.680  114   155.316
 115  108.342  116 -951.751  117   48.873  118    34.085  119 -299.426  120    66.819          0.000 121B     8.886
        0.000 121D   55.859 121E 1068.980 121F 1115.954  122 -960.637  123    91.049  124    0.923  125     2.183
 126    0.139  127    2.967  128    0.013  129     0.483  130    0.478  131     0.475  132    0.821  133     0.175
 134    0.416  135    0.402  136    0.950  137     0.271  138    0.040  139     0.755  140   70.966  141   124.658
 142 2339.340  143 2434.706  144 2673.266  145 3286.431  146  417.565  147   231.680  148 2586.071  149  2551.505
 150 -103.639  151  -86.245  152 ********  153 ********  154 ********  155 1913.511  156 8875.330  157  7889.750
 158  112.491  159    4.595  161    0.135

 106    12969.               109 2048251.
 145    3286.431             148   2586.071
 149    2551.505             152 -30867.011
 153 -43500.377              154  12633.362


                                    RUN 148, EVENT 442
                              ***    H2O2 APU PERFORMANCE    ***
      DATE  12-18-74
      TIME  16- 9- 1                                                              READING    442
                                                                                  BAROMETER  13.33 PSIA


      DATA IN ENGINEERING UNITS
RP66  856.06 RP67  553.62 DL68    13.75 DL69   10.67  SP5   858.01  SP7   505.67 DH68    13.97 DH69    11.13
SP18  103.49 SP63    15.78 SP27  549.93 SP58  534.39 SP62   143.86 SP64     0.33 SP66    -0.00  LP1 3765.08
 LP2   69.69 RT66  502.56 RT67  527.98  ST5   523.10  ST7   677.83 ST16   587.42 ST17   543.93 ST18   665.05
ST19  627.48 ST27  286.99 ST31  342.91 ST35  468.35 ST39   620.24 ST41   483.39 ST45   523.22 ST47 1369.19
ST51  810.99 ST56  301.03 ST57  746.62 ST58  749.87 ST62 1958.22 ST65 1440.31 ST66 1133.55 ST84   619.37
ST86  602.55  LT2  626.34  LT5  865.60  LT6  525.72 SN8162566.88 SO19    13.42 SO83     0.61 SO85     0.97
 LQ2   29.52  LQ5   15.32

      CALCULATIONS
 101    3.441  102    2.172  103    0.631          0.000 104A   94.485  105     3.565  106 ********  107     3.289
 160    1.369  108   11.494  109 ********  110     5.614  111  274.950  112    13.178  113  377.670  114   153.828
 115  103.372  116 -971.713  117   55.694  118    37.596  119 -353.414  120    63.656          0.000 121B     8.886
        0.000 121D   59.342 121E 1083.971 121F 1134.428  122 -980.600  123    94.556  124    1.170  125     2.270
 126    0.434  127    3.006  128    0.106  129     0.973  130    0.452  131     0.493  132    0.772  133     0.190
 134    0.382  135    0.418  136    0.922  137     0.334  138   -0.014  139     0.692  140  620.625  141   752.362
 142 1440.187  143 1588.111  144 1764.014  145 2166.673  146  462.051  147   257.390  148 3447.737  149  3774.322
 150   39.127  151  -80.694  152 ********  153 ********  154 ********  155 1888.195  156 8200.305  157  7875.162
 158  104.128  159    4.921  161    0.148

 106    13989.               109 1616174.
 145    2166.673             148   3447.737
 149    3774.322             152 -29587.259
 153 -43439.519              154  13852.255


                                    RUN 149, EVENT 449
                              ***    H2O2 APU PERFORMANCE    ***
      DATE  12-19-74
      TIME  13-51- 1                                                              READING    449
                                                                                  BAROMETER  13.36 PSIA


      DATA IN ENGINEERING UNITS
RP66  860.87 RP67  553.95 DL68     4.94 DL69    3.78  SP5   864.62  SP7   524.31 DH68     4.76 DH69     3.97
SP18  130.87 SP63     3.38 SP27  551.94 SP58  538.85 SP62    82.45 SP64    -9.91 SP66   -11.22  LP1 3868.08
 LP2   92.86 RT66  503.24 RT67  537.20  ST5   524.30  ST7   624.07 ST16   530.65 ST17   501.65 ST18   587.76
ST19  573.46 ST27  385.34 ST31  372.16 ST35  481.76 ST39   576.69 ST41   487.45 ST45   511.36 ST47 1232.17
ST51  767.49 ST56  728.50 ST57  763.62 ST58  749.87 ST62 1950.86 ST65 1312.65 ST66   987.68 ST84   586.14
ST86  559.67  LT2  541.01  LT5  865.60  LT6  523.10 SN8162708.63 SO19    13.08 SO83     0.44 SO85     0.63
 LQ2   20.32  LQ5   41.52

      CALCULATIONS
 101    1.988  102    1.293  103    0.650          0.000 104A   57.725  105     3.411  106 8330.153  107     3.327
 160    1.367  108   27.743  109 ********  110     3.282  111  195.330  112     9.079  113  266.982  114   109.248
 115   64.007  116 ********  117   56.046  118    32.768  119 ********  120    44.767          0.000 121B     6.281
        0.000 121D   51.522 121E 2839.977 121F 2885.218  122 ********  123    96.663  124    0.706  125     1.281
 126    0.197  127    1.791  128   -0.034  129     0.102  130    0.535  131     0.436  132    0.895  133     0.134
 134    0.553  135    0.671  136    0.899  137     0.405  138    0.057  139     0.416  140  -85.441  141    26.939
 142  733.295  143  595.738  144  634.187  145   788.439  146  160.575  147   113.771  148 1770.428  149  2299.167
 150  -95.726  151  -30.981  152 ********  153 ********  154 6945.416  155 1921.135  156 8549.433  157  7900.965
 158  108.207  159    3.095  161    0.140

 106     8330.               109 1963748.
 145     788.439             148   1770.428
 149    2299.167             152 **********
 153 **********              154   6945.416
```

```
                                   RUN 151, EVENT 464
                          ***   H2O2 APU PERFORMANCE    ***
      DATE   12-19-74                                                          READING    464
      TIME   15-47- 0                                                          BAROMETER  13.36 PSIA


      DATA IN ENGINEERING UNITS
RP66  872.91 RP67  561.96 DL68   13.75 DL69   13.76  SP5  862.42  SP7  493.71 DH68   34.84 DH69   26.75
SP18  127.87 SP63   33.06 SP27  544.45 SP58  512.09 SP62  232.57 SP64   -6.84 SP66   -9.40  LP1 3724.08
 LP2   92.21 RT66  505.49 RT67  528.10  ST5  521.78  ST7  695.05 ST16  565.62 ST17  532.54 ST18  721.91
ST19  660.13 ST27  207.54 ST31  333.43 ST35  468.16 ST39  632.26 ST41  491.24 ST45  510.51 ST47 1333.43
ST51  891.12 ST56  284.04 ST57  722.71 ST58  749.16 ST62 1953.42 ST65 1386.18 ST66 1010.39 ST84  614.44
ST86  589.10  LT2  693.22  LT5  865.60  LT6  521.07 SN8162425.13 SQ19   13.46 SQ83    0.55 SQ85    0.91
 LQ2   76.22  LQ5   42.92

      CALCULATIONS
 101     5.309  102     3.409  103     0.642            0.000 104A   205.024  105     2.551  106 ********  107     3.310
 160     1.368  108    37.671  109 ********  110     8.719  111   550.247  112    12.205  113   352.424  114   259.652
 115   213.316  116 ********  117    47.138  118    38.767  119  -513.311  120   161.516            0.000 1218     8.292
         0.000 1210    54.627 121E  3046.092 121F  3092.428  122 ********  123    91.270  124     2.455  125     2.854
 126     1.473  127     3.836  128     0.184  129     0.888  130     0.450  131     0.471  132     0.646  133     0.243
 134     0.259  135     0.444  136     0.939  137     0.429  138    -0.131  139     0.862  140  2105.487  141  3042.600
 142  2382.977  143  2529.751  144  2946.321  145  3591.857  146   345.185  147   178.983  148  7030.689  149  7112.042
 150   491.580  151  -141.804  152 ********  153 ********  154 ********  155  1905.874  156  8259.765  157  7888.100
 158   104.711  159     4.406  161     0.146

 106    21953.                 109 2082384.
 145   3591.857                148    7030.689
 149   7112.042                152 **********
 153 **********                154   18962.401

                                   RUN 151, EVENT 467
                          ***   H2O2 APU PERFORMANCE    ***
      DATE   12-19-74                                                          READING    467
      TIME   15-50- 1                                                          BAROMETER  13.36 PSIA


      DATA IN ENGINEERING UNITS
RP66  870.90 RP67  562.77 DL68   13.75 DL69   13.76  SP5  837.97  SP7  488.44 DH68   89.36 DH69   69.67
SP18  106.35 SP63   56.30 SP27  515.43 SP58  444.39 SP62  368.58 SP64   -3.56 SP66   -6.68  LP1 3586.04
 LP2   53.92 RT66  506.77 RT67  526.68  ST5  516.46  ST7  687.62 ST16  580.41 ST17  538.84 ST18  740.48
ST19  662.48 ST27  177.43 ST31  349.57 ST35  466.63 ST39  601.56 ST41  494.45 ST45  510.76 ST47 1298.58
ST51  951.92 ST56  308.78 ST57  725.07 ST59  748.04 ST62 1942.86 ST65 1382.15 ST66  987.68 ST84  626.83
ST86  601.50  LT2  711.64  LT5  865.60  LT6  554.89 SN8162330.63 SQ19   13.33 SQ83    0.60 SQ85    1.09
 LQ2  139.07  LQ5   42.97

      CALCULATIONS
 101     8.293  102     5.256  103     0.630            0.000 104A   350.877  105     2.306  106 ********  107     3.303
 160     1.368  108    38.940  109 ********  110    13.489  111   853.054  112    14.110  113   443.554  114   397.659
 115   361.313  116 ********  117    46.564  118    42.355  119  -295.633  120   286.598            0.000 1218    10.436
         0.000 1210    46.782 121E  2893.665 121F  2930.011  122 ********  123    89.373  124     4.610  125     3.622
 126     2.903  127     5.329  128     0.222  129     0.830  130     0.464  131     0.425  132     0.492  133     0.284
 134     0.189  135     0.483  136     0.904  137     0.452  138    -0.110  139     0.820  140  4571.349  141  6388.963
 142  3216.763  143  2957.607  144  3736.434  145  4484.395  146   451.478  147   262.174  148 ********  149 ********
 150   661.916  151  -215.914  152 ********  153 ********  154 ********  155  1898.336  156  8292.196  157  7880.647
 158   105.222  159     5.866  161     0.145

 106    33839.                 109 2086898.
 145   4484.395                148   12632.257
 149  11568.779                152  -82615.716
 153 **********                154   28745.708

                                   RUN 151, EVENT 469
                          ***   H2O2 APU PERFORMANCE    ***
      DATE   12-19-74                                                          READING    469
      TIME   15-52- 1                                                          BAROMETER  13.36 PSIA


      DATA IN ENGINEERING UNITS
RP66  872.10 RP67  559.99 DL68   10.14 DL69    7.59  SP5  873.24  SP7  498.98 DH68   10.36 DH69    7.85
SP18  107.59 SP63   11.96 SP27  557.16 SP58  542.36 SP62  129.46 SP64   -9.34 SP66  -11.22  LP1 3736.08
 LP2   76.48 RT66  506.65 RT67  528.81  ST5  518.64  ST7  695.05 ST16  588.38 ST17  559.15 ST18  750.13
ST19  702.92 ST27  205.20 ST31  236.27 ST35  464.26 ST39  705.18 ST41  485.33 ST45  533.51 ST47 1329.41
ST51  794.51 ST56  284.04 ST57  749.57 ST58  747.03 ST62 1955.02 ST65 1375.46 ST66 1108.23 ST84  631.34
ST86  603.21  LT2  708.12  LT5  865.60  LT6  526.68 SN8162535.38 SQ19   13.75 SQ83    0.69 SQ85    1.03
 LQ2   28.32  LQ5   43.02

      CALCULATIONS
 101     2.858  102     1.884  103     0.659            0.000 104A    91.645  105     3.104  106 ********  107     3.344
 160     1.367  108    35.504  109 ********  110     4.742  111   294.350  112    14.174  113   349.488  114   143.314
 115    99.868  116 ********  117    48.778  118    33.928  119  -950.606  120    60.477            0.000 1218     8.223
         0.000 1210    51.669 121E  2906.209 121F  2949.655  122 ********  123    92.415  124     0.937  125     1.920
 126     0.251  127     2.606  128     0.052  129     0.866  130     0.486  131     0.468  132     0.842  133     0.165
 134     0.467  135     0.283  136     0.947  137     0.315  138     0.010  139     0.763  140   276.164  141   434.690
 142  2122.818  143  2140.848  144  2345.542  145  2872.906  146   463.469  147   187.160  148  2597.840  149  2709.072
 150   -25.388  151   -79.772  152 ********  153 ********  154 ********  155  1932.934  156  8820.116  157  7906.201
 158   111.559  159     3.920  161     0.136

 106    12130.                 109 2048245.
 145   2872.906                148    2597.840
 149   2709.072                152 **********
 153 **********                154   11248.751
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                                   RUN 151, EVENT 474
                           ***   H202 APU PERFORMANCF   ***
      DATE  12-19-74                                                                       READING   474
      TIME  15-87- 0                                                                       BAROMETER  13.36 PSIA


      DATA IN ENGINEERING UNITS
RP66  871.30 RP67  559.01 DL68     6.53 DL69    4.72  SP5  873.44  SP7  512.35 DH68    6.63 DH69    4.85
SP18  129.70 SP63     6.33 SP27  559.44 SP58  548.71 SP62  107.96 SP64   -9.82 SP66  -11.41  LP1 3761.08
 LP2   94.81 RT66  506.10 RT67  528.75  ST5  521.42  ST7  695.36 ST16  605.37 ST17  558.06 ST18  769.52
ST19  728.34 ST27  222.87 ST31  240.42 ST35  470.26 ST39  738.87 ST41  487.38 ST45  553.43 ST47 1318.24
ST51  762.15 ST56  688.62 ST57  757.06 ST58  745.71 ST62 1955.02 ST65 1361.A1 ST66 1142.80 ST84  637.35
ST86  611.42  LT2  713.37  LT5  865.60  LT6  521.49 SN8162661.38 SO19   13.92 SO83    0.72 SO85    1.08
 LO2   20.82  LO5   42.32

      CALCULATIONS
 101    2.249  102    1.494  103    0.664          0.000 104A   59.460  105    3.778  106 9622.267  107    3.355
 160    1.366  108   34.246  109 ********  110    3.744  111  230.479  112   14.914  113  423.372  114  115.104
 115   69.421  116 ********  117   50.085  118   30.120  119 ********  120   44.545          0.000 1218    9.961
        0.000 121D   55.644 121E 2878.874 121F 2924.557  122 ********  123   93.265  124    0.613  125    1.635
 126    0.155  127    2.094  128    0.032  129    0.136  130    0.461  131    0.504  132    0.897  133    0.137
 134    0.559  135    0.400  136    0.946  137    0.270  138    0.048  139    0.738  140  122.798  141   39.992
 142 1687.868  143 1934.759  144 2065.718  145 2580.337  146  499.215  147  320.709  148 1636.820  149 1760.363
 150  -89.407  151  -62.395  152 ********  153 ********  154 9142.775  155 1940.328  156 9489.029  157 7910.090
 158  119.961  159    4.976  161    0.126

 106    9622.                     109 2031210.
 145   2580.337                   148   1636.820
 149   1760.363                   152 **********
 153 **********                   154   9142.775
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                                   RUN 154, EVENT 501
                           ***   H202 APU PERFORMANCF   ***
      DATE   1- 8-75                                                                       READING   501
      TIME  15-21-31                                                                       BAROMETER  13.21 PSIA


      DATA IN ENGINEERING UNITS
RP66  864.28 RP67  556.89 DL68     4.67 DL69    3.26  SP5  862.02  SP7  515.60 DH68    4.76 DH69    3.52
SP18  121.90 SP63     3.77 SP27  558.23 SP58  546.95 SP62   84.85        -10.97 SP64  -10.97  LP1 3780.09
 LP2   82.50 RT66  493.09 RT67  518.73  ST5  511.00  ST7  681.31 ST16  570.57 ST17  525.61 ST18  583.00
ST19  707.49 ST27   50.81 ST31  349.70 ST35  466.18 ST39  572.61 ST41  472.17 ST45  526.10 ST47 1200.80
ST51 1100.07 ST56  284.04 ST57  731.63 ST58  747.94 ST62 1952.78 ST65 1347.06 ST66  789.74 ST84  616.85
ST86  582.83  LT2  522.86  LT5  512.77  LT6  517.71 SN8162866.13 SO19   13.08 SO83    0.54 SO85    0.83
 LO2   18.87  LO5   67.72

      CALCULATIONS
 101    1.880  102    1.273  103    0.676          0.000 104A   57.715  105    3.278  106 8195.854  107    3.380
 160    1.365  108   43.847  109 ********  110    3.153  111  200.763  112   11.571  113  355.030  114   98.253
 115   66.069  116   89.848  117   49.194  118   32.908  119   44.753  120   28.222          0.000 1218    8.353
        0.000 121D   40.537 121E  -15.425 121F   16.758  122   81.494  123   97.576  124    1.599  125    0.280
 126    0.849  127    1.031  128    0.284  129    0.777  130    0.522  131    0.450  132    0.911  133   -1.065
 134    0.548  135    0.456  136    0.821  137    0.678  138   -0.073  139    0.771  140 1917.073  141 2374.881
 142  731.586  143  635.432  144  673.719  145 ********  146  342.413  147  230.507  148 3753.902  149 3722.486
 150  107.350  151  -52.036  152 8009.852  153 2789.796  154 5220.057  155 1964.162  156 9106.696  157 7931.269
 158  114.820  159    4.088  161    0.131

 106    8195.                     109 2100755.
 145  -7403.449                   148   3753.902
 149   3722.486                   152   8009.852
 153   2789.796                   154   5220.057
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                                   RUN 154, EVENT 510
                           ***   H202 APU PERFORMANCF   ***
      DATE   1- 8-75                                                                       READING   510
      TIME  15-25-56                                                                       BAROMETER  13.21 PSIA


      DATA IN ENGINEERING UNITS
RP66  875.11 RP67  557.38 DL68     8.52 DL69    6.18  SP5  870.23  SP7  506.88 DH68    8.50 DH69    6.63
SP18  123.15 SP63     9.58 SP27  555.69 SP58  543.31 SP62  118.46        -10.83 SP64  -10.83  LP1 3757.08
 LP2   79.04 RT66  493.53 RT67  518.79  ST5  510.15  ST7  693.69 ST16  584.23 ST17  523.88 ST18  570.06
ST19  725.26 ST27   49.31 ST31  338.36 ST35  465.22 ST39  553.04 ST41  471.48 ST45  521.54 ST47 1198.11
ST51 1118.19 ST56  284.04 ST57  727.02 ST58  747.13 ST62 1958.22 ST65 1361.36 ST66  790.49 ST84  622.31
ST86  589.83  LT2  525.72  LT5  511.08  LT6  519.45 SN8162755.88 SO19   12.96 SO83    0.55 SO85    0.91
 LO2   29.47  LO5   67.57

      CALCULATIONS
 101    2.596  102    1.734  103    0.667          0.000 104A   57.477  105    4.521  106 ********  107    3.362
 160    1.366  108   55.351  109 ********  110    4.331  111  287.187  112   12.250  113  415.147  114  133.715
 115   67.246  116  138.873  117   46.712  118   23.415  119   48.356  120   63.249          0.000 1218    9.768
        0.000 121D   76.237 121E  -61.858 121F    4.610  122  129.104  123   96.570  124    2.290  125    0.386
 126    1.217  127    1.379  128    0.270  129    0.780  130    0.590  131    0.377  132    0.837  133   -1.480
 134    0.441  135    0.537  136    0.805  137    0.679  138   -0.092  139    0.846  140 2565.493  141 3483.302
 142 1097.736  143  708.866  144  768.526  145 ********  146  434.769  147  329.045  148 5387.035  149 5265.619
 150  182.759  151  -76.390  152 ********  153 4718.431  154 7213.751  155 1947.668  156 8903.242  157 7917.641
 158  112.448  159    5.132  161    0.134

 106   11164.                     109 2188178.
 145  -9155.925                   148   5387.035
 149   5265.619                   152  11932.183
 153   4718.431                   154   7213.751
// END   17 MAR 75 11.144 HRS
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RUN 160, EVENT 525

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                                   ***   H202 APU PERFORMANCE   ***
     DATE   1-10-75                                                                      READING   525
     TIME  16- 0-31                                                                    BAROMETER  13.27 PSIA

     DATA IN ENGINEERING UNITS
RP66  883.54 RP67  555.26 DL68     4.44 DL69     3.33  SP5   886.87  SP7   523.30 DH68     4.41 DH69     3.38
SP18  125.60 SP63     3.80 SP27  555.02 SP58  540.33 SP62    82.45          -10.61 SP64  -10.61  LP1 3837.08
 LP2   88.19 RT66  498.58 RT67  522.50  ST5  516.46  ST7   637.93 ST16  539.54 ST17  497.41 ST18  580.18
ST19  696.38 ST27   59.62 ST31  377.16 ST35  472.30 ST39  571.20 ST41  478.49 ST45  509.41 ST47 1126.78
ST51 1096.21 ST56  284.04 ST57  744.59 ST58  777.30 ST62 1958.54 ST65 1328.74 ST66  707.56 ST84  595.68
ST86  565.10  LT2  525.72  LT5  518.13  LT6  525.84 SN8162551.13 SQ19   13.07 SQ83    0.40 SQ85    0.63
 LQ2   20.07  LQ5   18.77

     CALCULATIONS
 101    1.892  102    1.247  103    0.659           0.000 104A   57.705  105    3.265  106 8033.188  107    3.345
 160    1.367  108   36.007  109 ********  110    3.140  111  195.683  112    8.778  113  297.173  114  102.715
 115   64.697  116   50.212  117   52.632  118   33.062  119   25.660  120   43.908           0.000 121B    6.992
        0.000 121D   45.010 121E   21.476 121F   59.494  122   43.220  123   97.389  124    1.798  125    0.093
 126    0.819  127    1.073  128    0.306  129    0.783  130    0.490  131    0.477  132    0.916  133   -1.077
 134    0.506  135    0.690  136    0.753  137    0.758  138   -0.143  139    0.532  140 2037.569  141 2280.600
 142  606.129  143  589.779  144  629.638  145 ********  146  198.081  147  160.085  148 3855.276  149 4165.544
 150  216.661  151  -36.374  152 5898.680  153 1207.234  154 4691.446  155 1963.352  156 8927.633  157 7970.683
 158  112.005  159    3.604  161    0.134

 106    8033.                 109 2056327.
 145  -6849.380               148   3855.276
 149   4165.544               152   5898.680
 153   1207.234               154   4691.446
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RUN 160, EVENT 529

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                                   ***   H202 APU PERFORMANCE   ***
     DATE   1-10-75                                                                      READING   529
     TIME  16- 2-31                                                                    BAROMETER  13.27 PSIA

     DATA IN ENGINEERING UNITS
RP66  882.53 RP67  555.09 DL68     8.69 DL69     6.32  SP5   884.06  SP7   510.33 DH68     8.54 DH69     6.55
SP18  134.02 SP63    10.91 SP27  552.07 SP58  535.33 SP62   113.56          -10.02 SP64  -10.02  LP1 3822.08
 LP2   88.02 RT66  496.40 RT67  521.97  ST5  515.74  ST7  1098.40 ST16  551.83 ST17  501.16 ST18  578.44
ST19  692.06 ST27   53.46 ST31  386.99 ST35  470.33 ST39  560.99 ST41  477.11 ST45  505.75 ST47 1173.19
ST51 1111.85 ST56  284.04 ST57  729.59 ST58  750.88 ST62 1961.10 ST65 1351.08 ST66  757.04 ST84  604.37
ST86  572.27  LT2  536.43  LT5  517.95  LT6  533.31 SN8162488.13 SQ19   13.03 SQ83    0.42 SQ85    0.69
 LQ2   30.22  LQ5   16.67

     CALCULATIONS
 101    2.613  102    1.751  103    0.670           0.000 104A   96.142  105    2.723  106 ********  107    3.366
 160    1.366  108   39.072  109 ********  110    4.364  111  274.648  112    9.437  113  335.172  114  137.508
 115  104.029  116   82.925  117   50.253  118   37.877  119   30.193  120   65.847           0.000 121B    7.886
        0.000 121D   41.366 121E   28.989 121F   62.469  122   75.039  123   96.495  124    2.372  125    0.240
 126    1.206  127    1.406  128    0.315  129    0.782  130    0.478  131    0.482  132    0.858  133   -1.050
 134    0.383  135    0.678  136    0.789  137    0.702  138   -0.099  139    2.724  140 2955.903  141 3424.575
 142  735.682  143  737.238  144  797.451  145 ********  146  253.705  147  208.298  148 5500.128  149 5509.160
 150  194.792  151 -244.861  152 9335.375  153 2391.721  154 6943.654  155 1955.454  156 8511.464  157 7928.665
 158  107.350  159    4.152  161    0.141

 106   11273.                 109 2076839.
 145  -6615.772               148   5500.128
 149   5509.160               152   9335.375
 153   2391.721               154   6943.654
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RUN 160, EVENT 534

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                                   ***   H202 APU PERFORMANCE   ***
     DATE   1-10-75                                                                      READING   534
     TIME  16- 4-56                                                                    BAROMETER  13.27 PSIA

     DATA IN ENGINEERING UNITS
RP66  881.93 RP67  555.91 DL68    13.75 DL69    13.76  SP5   874.24  SP7   498.78 DH68    30.63 DH69    23.18
SP18  138.56 SP63    28.75 SP27  541.77 SP58  511.28 SP62   219.67           -7.93 SP64   -7.93  LP1 3760.08
 LP2   81.97 RT66  498.40 RT67  522.27  ST5  511.12  ST7   696.41 ST16  555.81 ST17  511.63 ST18  588.93
ST19  728.55 ST27   49.93 ST31  317.90 ST35  469.76 ST39  546.61 ST41  479.69 ST45  499.97 ST47 1174.76
ST51 1129.49 ST56  317.39 ST57  733.78 ST58  750.88 ST62 1962.38 ST65 1383.05 ST66  785.46 ST84  612.52
ST86  580.58  LT2  556.45  LT5  517.65  LT6  550.67 SN8162377.88 SQ19   12.93 SQ83    0.45 SQ85    0.81
 LQ2   74.92  LQ5   18.72

     CALCULATIONS
 101    4.957  102    3.245  103    0.654           0.000 104A  201.947  105    2.437  106 ********  107    3.335
 160    1.367  108   43.598  109 ********  110    8.202  111  529.133  112   10.668  113  368.719  114  247.798
 115  210.623  116  160.208  117   46.857  118   39.805  119   30.277  120  160.783           0.000 121B    8.675
        0.000 121D   45.850 121E   59.090 121F   96.265  122  151.532  123   94.720  124    4.624  125    0.332
 126    2.415  127    2.541  128    0.248  129    0.752  130    0.663  131    0.292  132    0.644  133   -1.171
 134    0.266  135    0.580  136    0.764  137    0.676  138   -0.076  139    0.832  140 4555.440  141 6748.061
 142 2502.687  143 1116.420  144 1283.827  145 ********  146  341.932  147  206.517  148 ********  149 ********
 150  296.765  151 -144.303  152 ********  153 5156.318  154 ********  155 1928.829  156 8316.773  157 7908.300
 158  105.165  159    4.745  161    0.145

 106   20891.                 109 2128777.
 145  -8167.028               148  10834.966
 149  10522.637               152  18833.086
 153   5156.318               154  13676.767
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                                        RUN 161, EVENT 541
                                   ***   H2O2 APU PERFORMANCE   ***
     DATE    1-13-75                                                                    READING   541
     TIME  14-27-56                                                                     BAROMETER  13.41 PSIA


     DATA IN ENGINEERING UNITS
RP66  873.51 RP67  556.73 DL68    4.67 DL69    3.54  SP5  873.04  SP7  520.87 DH68    4.67 DH69    3.52
SP18  126.08 SP63    3.71 SP27  557.70 SP58  541.95 SP62   81.85       -10.78 SP64  -10.78  LP1 3846.08
 LP2   85.58 RT66  511.99 RT67  535.90  ST5  528.98  ST7  633.47 ST16  535.49 ST17  493.90 ST18  578.66
ST19  710.07 ST27   63.20 ST31  336.79 ST35  471.54 ST39  573.12 ST41  478.24 ST45  507.22 ST47 1130.16
ST51 1062.75 ST56  284.04 ST57  728.25 ST58  777.60 ST62 1964.62 ST65 1330.53 ST66  707.82 ST84  593.40
ST86  564.19  LT2  525.01  LT5  519.45  LT6  522.74 SN8162740.13 SQ19   13.12 SQ83    0.43 SQ85    0.62
 LQ2   21.07  LQ5   87.67

     CALCULATIONS
 101     1.929  102     1.255  103     0.650          0.000 104A    57.797  105     3.306  106 8083.552  107     3.327
 160     1.367  108    36.118  109 ********  110     3.185  111   199.878  112     8.927  113  311.199  114  105.435
 115    65.120  116    79.449  117    52.804  118    32.580  119    39.748  120    46.238           0.000 121B    7.322
         0.000 121D    47.637 121E    -7.006 121F    33.308  122    72.126  123    97.761  124     1.720  125     0.208
 126     0.828  127     1.100  128     0.273  129     0.779  130     0.570  131     0.401  132     0.948  133    -1.226
 134     0.506  135     0.726  136     0.756  137     0.756  138    -0.247  139     0.524  140 1798.226  141 2209.953
 142   866.929  143   615.435  144   659.419  145 ********  146   189.398  147   160.247  148 3720.996  149 4256.640
 150   333.254  151   -31.488  152 7190.185  153 2405.975  154 4784.210  155 1948.918  156 8759.856  157 7960.293
 158   110.044  159     3.682  161     0.138

 106     8083.                 109 2070828.
 145 -7822.262                 148   3720.996
 149  4256.640                 152   7190.185
 153  2405.975                 154   4784.210
```

```
                                        RUN 163, EVENT 548
                                   ***   H2O2 APU PERFORMANCE   ***
     DATE    1-13-75                                                                    READING   548
     TIME  15-55-56                                                                     BAROMETER  13.41 PSIA


     DATA IN ENGINEERING UNITS
RP66  873.31 RP67  560.65 DL68    4.81 DL69    3.38  SP5  872.64  SP7  520.26 DH68    4.67 DH69    3.40
SP18  131.24 SP63    4.16 SP27  559.03 SP58  544.12 SP62   82.95       -10.72 SP64  -10.72  LP1 3839.08
 LP2   89.97 RT66  511.26 RT67  528.81  ST5  526.22  ST7  632.49 ST16  536.26 ST17  492.10 ST18  574.11
ST19  562.93 ST27   56.02 ST31  272.21 ST35  469.50 ST39  567.78 ST41  475.53 ST45  506.85 ST47 -211.59
ST51 1097.80 ST56  284.04 ST57  733.78 ST58  750.38 ST62 1961.74 ST65 1331.87 ST66  736.74 ST84  594.12
ST86  566.25  LT2  519.27  LT5  509.87  LT6  513.80 SN8162724.38 SQ19   13.03 SQ83    0.40 SQ85    0.62
 LQ2   23.57  LQ5   87.62

     CALCULATIONS
 101     1.904  102     1.275  103     0.669          0.000 104A    57.622  105     3.311  106 8211.525  107     3.366
 160     1.366  108    35.750  109 ********  110     3.180  111   197.311  112     8.753  113  315.333  114  103.445
 115    65.042  116    89.833  117    52.640  118    32.964  119    45.528  120    51.566           0.000 121B    7.419
         0.000 121D    45.822 121E   -17.372 121F    21.030  122    82.414  123    97.427  124    -1.566  125     3.471
 126     0.851  127     1.052  128     0.207  129     0.781  130     0.667  131     0.312  132     0.939  133     0.106
 134     0.515  135     0.727  136    -0.870  137     0.721  138    -0.079  139     0.511  140 1431.899  141 2376.072
 142  1235.570  143   590.953  144   629.976  145   613.656  146   202.168  147   166.719  148 3927.781  149 4019.589
 150   110.631  151   -32.530  152 7794.471  153 2872.632  154 4921.839  155 1954.240  156 8875.340  157 7927.057
 158   111.962  159     3.901  161     0.135

 106     8211.                 109 2047546.
 145   613.656                 148   3927.781
 149  4019.589                 152   7794.471
 153  2872.632                 154   4921.839
```

```
                                        RUN 170, EVENT 573
                                   ***   H2O2 APU PERFORMANCE   ***
     DATE    1-14-75                                                                    READING   573
     TIME  14- 3-31                                                                     BAROMETER  13.39 PSIA


     DATA IN ENGINEERING UNITS
RP66  869.30 RP67  562.12 DL68   13.75 DL69   13.76  SP5  843.18  SP7  487.03 DH68   68.67 DH69   47.58
SP18  149.58 SP63   46.72 SP27  530.14 SP58  477.90 SP62  314.98        -5.80 SP64   -5.80  LP1 3712.08
 LP2   82.54 RT66  527.86 RT67  526.38  ST5  527.54  ST7  696.93 ST16  556.73 ST17  517.11 ST18  604.59
ST19  682.91 ST27   52.28 ST31  409.13 ST35  468.55 ST39  538.55 ST41  480.82 ST45  496.77 ST47 1169.37
ST51 1127.68 ST56  394.83 ST57  737.97 ST58  749.77 ST62 1962.38 ST65 1394.90 ST66  802.27 ST84  616.14
ST86  586.92  LT2  574.09  LT5  520.77  LT6  567.61 SN8162440.88 SQ19   12.94 SQ83    0.47 SQ85    0.90
 LQ2  117.92  LQ5   21.72

     CALCULATIONS
 101     6.958  102     4.573  103     0.657          0.000 104A   299.228  105     2.312  106 ********  107     3.340
 160     1.367  108    43.270  109 ********  110    11.531  111   742.186  112    11.517  113  396.522  114  340.838
 115   308.558  116   247.681  117    45.956  118    41.574  119    33.371  120   249.716           0.000 121B    9.329
         0.000 121D    41.610 121E    70.207 121F   102.487  122   238.351  123    93.916  124     6.527  125     0.431
 126     3.700  127     3.258  128     0.331  129     0.681  130     0.459  131     0.446  132     0.514  133    -0.575
 134     0.210  135     0.521  136     0.748  137     0.659  138    -0.056  139     0.804  140 8413.031  141 9379.653
 142  1405.650  143  1352.390  144 1642.766  145 ********  146   377.280  147   200.407  148 ********  149 ********
 150   287.411  151  -185.913  152 ********  153 8487.173  154 ********  155 1932.217  156 8339.155  157 7909.385
 158   105.433  159     5.350  161     0.144

 106    29442.                 109 2123864.
 145 -4475.605                 148  15239.978
 149 14657.011                 152  28107.818
 153  8487.173                 154  19620.649
```

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                                        RUN 170, EVENT 579
                                 ***    H202 APU PERFORMANCF    ***
      DATE    1-14-75                                                              READING    579
      TIME   14- 6-31                                                              BAROMETER  13.39 PSIA


      DATA IN ENGINEEHING UNITS
RP66  869.70 RP67  563.43 DL68   13.75 DL69   13.76  SP5  839.77  SP7  482.97 DH68   77.54 DH69   52.64
SP18  133.29 SP63   49.73 SP27  527.46 SP58  470.47 SP62  339.78          1.19 SP64   1.19  LP1 3689.08
 LP2   64.61 RT66  528.75 RT67  527.81  ST5  530.89  ST7  694.11 ST16  573.01 ST17  533.78 ST18  612.58
ST19  671.70 ST27   52.58 ST31  406.59 ST35  467.33 ST39  540.13 ST41  480.19 ST45  499.48 ST47 1217.84
ST51 1134.68 ST56  405.10 ST57  737.36 ST58  748.45 ST62 1960.46 ST65 1429.79 ST66  839.65 ST84  625.85
ST86  594.29  LT2  592.10  LT5  520.71  LT6  575.16 SN8162456.63 SQ19   12.93 SQ83   0.54 SQ85    0.96
 LQ2  117.72  LQ5   21.77

      CALCULATIONS
 101     7.281  102     4.828  103   0.663          0.000 104A  298.740  105     2.432  106 ********  107     3.352
 160     1.366  108    24.201  109 ********  110   12.109  111  701.006  112    12.598  113  395.305  114   333.888
 115   304.041  116   284.029  117   47.663  11A   43.942  119   40.517  120   248.944         0.000 121B     9.301
         0.000 1210    35.148 121E   33.313 121F   59.160  122  274.728  123    93.429  124    6.438  125     0.842
 126     3.965  127     3.315  128    0.327  129    0.674  130    0.454  131     0.448  132    0.501  133    -0.407
 134     0.207  135     0.422  136    0.772  137    0.634  138   -0.053  139     0.790  140 8732.236  141 ********
 142  1503.857  143  1469.251  144 1787.550  145 ********  146  477.559  147   219.834  148 ********  149 ********
 150   282.718  151  -189.131  152 ********  153 9888.395  154 ********  155  1940.983  156 8541.251  157  7914.323
 158   107.921  159     5.019  161    0.140

 106   31083.                 109 1910348.
 145  -3356.442               148  16065.080
 149  15300.086               152  31405.901
 153   9888.395               154  21517.507

                                        RUN 170, EVENT 585
                                 ***    H202 APU PERFORMANCF    ***
      DATE    1-14-75                                                              READING    585
      TIME   14- 8-56                                                              BAROMETER  13.39 PSIA


      DATA IN ENGINEERING UNITS
RP66  870.50 RP67  561.30 DL68   13.75 DL69   13.76  SP5  856.00  SP7  486.42 DH68   39.45 DH69   28.56
SP18  128.90 SP63   33.33 SP27  544.98 SP58  512.49 SP62  252.07          0.70 SP64   0.70  LP1 3741.08
 LP2   69.08 RT66  528.46 RT67  530.65  ST5  532.20  ST7  703.28 ST16  589.94 ST17  528.70 ST18  606.53
ST19  573.92 ST27   45.76 ST31  360.08 ST35  465.99 ST39  551.94 ST41  477.61 ST45  506.36 ST47 1272.65
ST51 1134.23 ST56  334.24 ST57  730.10 ST58  747.74 ST62 1960.78 ST65 1449.26 ST66  863.34 ST84  630.25
ST86  596.46  LT2  572.27  LT5  520.65  LT6  563.90 SN8162472.38 SQ19   13.04 SQ83   0.58 SQ85    0.98
 LQ2   74.82  LQ5   21.72

      CALCULATIONS
 101     5.462  102     3.533  103    0.646          0.000 104A  201.710  105     2.675  106 ********  107     3.320
 160     1.368  108    18.819  109 ********  110    8.995  111  497.195  112    13.094  113  457.491  114   241.404
 115   212.475  116   232.386  117   48.437  11A   42.734  119   46.739  120   160.301         0.000 121B    10.764
         0.000 1210    39.694 121E   -9.147 121F   19.782  122  221.622  123    94.736  124    4.475  125     0.986
 126     2.759  127     2.702  128    0.286  129    0.734  130    0.552  131     0.387  132    0.611  133     0.252
 134     0.255  135     0.545  136    0.812  137    0.621  138   -0.089  139     0.864  140 5853.695  141  7602.343
 142  1936.418  143  1366.285  144 1582.054  145 1780.362  146  532.163  147   358.353  148 ********  149 ********
 150   337.257  151  -145.077  152 ********  153 7836.893  154 ********  155  1912.528  156 8642.541  157  7891.349
 158   109.519  159     5.699  161    0.139

 106   22748.                 109 1823961.
 145   1780.362               148  11922.419
 149  11401.037               152  24440.602
 153   7836.893               154  16603.712


                                        RUN 170, EVENT 593
                                 ***    H202 APU PERFORMANCF    ***
      DATE    1-14-75                                                              READING    593
      TIME   14-11-41                                                              BAROMETER  13.39 PSIA


      DATA IN ENGINEERING UNITS
RP66  871.50 RP67  559.18 DL68   13.75 DL69    9.93  SP5  868.63  SP7  499.59 DH68   14.71 DH69   10.37
SP18  120.04 SP63   14.97 SP27  555.29 SP58  541.41 SP62  160.66          0.31 SP64   0.31  LP1 3808.08
 LP2   75.99 RT66  527.75 RT67  531.83  ST5  533.51  ST7  705.56 ST16  589.94 ST17  546.03 ST18  603.71
ST19  578.89 ST27   50.52 ST31  367.87 ST35  465.61 ST39  573.86 ST41  475.15 ST45  523.34 ST47 1364.05
ST51 1096.89 ST56  284.04 ST57  724.66 ST58  746.93 ST62 1955.98 ST65 1485.99 ST66  956.62 ST84  633.67
ST86  598.62  LT2  558.40  LT5  520.17  LT6  546.55 SN8162503.88 SQ19   13.24 SQ83   0.60 SQ85    0.96
 LQ2   29.72  LQ5   21.72

      CALCULATIONS
 101     3.326  102     2.194  103    0.659          0.000 104A   94.959  105     3.488  106 ********  107     3.345
 160     1.367  108    12.692  109 ********  110    5.521  111  274.428  112    13.029  113  379.929  114   135.279
 115   103.898  116   149.912  117   49.232  118   37.859  119   54.627  120    64.725         0.000 121B     8.939
         0.000 1210    40.320 121E  -37.074 121F   -5.694  122  140.973  123    96.925  124    2.269  125     1.057
 126     1.523  127     1.803  128    0.303  129    0.776  130    0.474  131     0.479  132    0.783  133     0.179
 134     0.419  135     0.382  136    0.873  137    0.549  138   -0.116  139     0.900  140 3591.664  141  4243.739
 142  1090.493  143  1104.203  144 1212.112  145 1388.133  146  541.229  147   257.363  148 6642.794  149  6293.004
 150   259.233  151   -90.614  152 ********  153 4779.260  154 ********  155  1933.588  156 9232.742  157  7906.563
 158   116.773  159     4.361  161    0.130

 106   14127.                 109 1640278.
 145   1388.133               148   6642.794
 149   6293.004               152  16023.596
 153   4779.260               154  11244.336
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RUN 170, EVENT 597

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                                   ***   H2O2 APU PERFORMANCE   ***
DATE   1-14-75
TIME  14-12-56                                                                    READING    597
                                                                                  BAROMETER  13.39 PSIA

      DATA IN ENGINEERING UNITS
RP66   871.70 RP67   559.01 DL68     9.06 DL69     6.12  SP5   869.43  SP7   507.09 DH68     9.19 DH69     6.40
SP18   120.07 SP63    10.54 SP27   559.70 SP58   549.25 SP62   127.66           0.21 SP64     0.21  LP1 3831.08
 LP2    81.11 RT66   527.45 RT67   531.95  ST5   533.87  ST7   705.56 ST16   599.73 ST17   556.79 ST18   614.28
ST19   591.11 ST27    48.34 ST31   334.67 ST35   465.61 ST39   592.06 ST41   474.45 ST45   534.82 ST47 1392.44
ST51 1067.09 ST56   284.04 ST57   725.48 ST58   747.03 ST62 1954.06 ST65 1501.23 ST66   987.68 ST84   634.37
ST86   600.01  LT2   556.16  LT5   520.35  LT6   536.78 SN8162566.88 SQ19    13.33 SQ83     0.63 SQ85     0.99
 LQ2    17.47  LQ5    21.62

      CALCULATIONS
 101     2.555  102     1.726  103     0.675            0.000 104A    58.231  105     4.412  106 ********  107     3.378
 160     1.365  108    10.357  109 ********  110     4.282  111   198.982  112    13.411  113   337.796  114   100.236
 115    66.179  116   103.257  117    50.411  118    33.259  119    51.892  120    29.169                0.000 121B     7.948
         0.000 121D    42.004 121E   -29.129 121F     4.927  122    95.309  123    97.665  124     1.586  125     0.969
 126     1.114  127     1.440  128     0.281  129     0.768  130     0.508  131     0.456  132     0.850  133     0.155
 134     0.481  135     0.342  136     0.887  137     0.531  138    -0.112  139     0.896  140 2502.934  141 2989.484
 142 1114.381  143 1010.132  144 1086.984  145 1320.806  146   520.091  147   261.055  148 4739.067  149 4697.066
 150   192.710  151   -71.150  152 ********  153 2963.664  154 8932.157  155 1961.077  156 9646.714  157 7927.700
 158   121.683  159     3.694  161     0.124

 106    11116.                 109 1533393.
 145    1320.806               148    4739.067
 149    4697.066               152   11895.820
 153    2963.664               154    8932.157
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RUN 180, EVENT 631

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                                   ***   H2O2 APU PERFORMANCE   ***
DATE   1-22-75
TIME  15- 1-30                                                                    READING    631
                                                                                  BAROMETER  13.41 PSIA

      DATA IN ENGINEERING UNITS
RP66   869.70 RP67   554.93 DL68    13.75 DL69    13.76  SP5   840.17  SP7   487.63 DH68    77.02 DH69    57.45
SP18   126.08 SP63    52.62 SP27   514.63 SP58   454.93 SP62   333.28           1.27 SP64     1.27  LP1 3603.05
 LP2    66.80 RT66   511.99 RT67   523.52  ST5   517.92  ST7   688.56 ST16   549.69 ST17   526.20 ST18   743.18
ST19   667.71 ST27    53.16 ST31   364.04 ST35   469.06 ST39   615.15 ST41   496.24 ST45   507.34 ST47 1262.82
ST51 1083.71 ST56   365.95 ST57   733.58 ST58   749.57 ST62 1944.46 ST65 1426.88 ST66   909.31 ST84   615.15
ST86   586.08  LT2   714.37  LT5   526.26  LT6   557.14 SN8162598.38 SQ19    13.37 SQ83     0.52 SQ85     0.91
 LQ2   120.17  LQ5    13.27

      CALCULATIONS
 101     7.537  102     4.891  103     0.649            0.000 104A   304.723  105     2.447  106 ********  107     3.324
 160     1.368  108    23.589  109 ********  110    12.429  111   715.004  112    12.095  113   370.285  114   336.628
 115   313.436  116   176.518  117    47.049  118    43.836  119    24.687  120   247.939                0.000 121B     8.712
         0.000 121D    31.905 121E   145.630 121F   168.823  122   167.805  123    89.495  124     5.750  125     1.786
 126     3.676  127     3.860  128     0.301  129     0.696  130     0.418  131     0.473  132     0.532  133     0.275
 134     0.207  135     0.439  136     0.821  137     0.562  138    -0.074  139     0.791  140 7970.828  141 9100.251
 142 2653.188  143 3016.490  144 3713.218  145 4361.277  146   281.575  147   124.849  148 ********  149 ********
 150   421.813  151  -200.344  152 ********  153 3418.525  154 ********  155 1917.960  156 8168.820  157 7898.003
 158   103.427  159     4.699  161     0.147

 106    31493.                 109 1898380.
 145    4361.277               148   15102.356
 149   13899.759               152   27589.673
 153    3418.525               154   24171.149
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RUN 187, EVENT 688

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                                   ***   H2O2 APU PERFORMANCE   ***
DATE   2- 5-75
TIME  11- 3-46                                                                    READING    688
                                                                                  BAROMETER  13.39 PSIA

      DATA IN ENGINEERING UNITS
RP66   873.71 RP67   550.03 DL68    11.65 DL69     9.45  SP5   870.43  SP7   512.96 DH68    11.63 DH69     9.69
SP18   117.22 SP63    14.97 SP27   544.71 SP58   524.66 SP62   130.76           0.26 SP64     0.26  LP1 3756.08
 LP2    80.95 RT66   488.50 RT67   523.34  ST5   516.59  ST7   657.33 ST16   525.13 ST17   481.89 ST18   574.14
ST19   552.29 ST27    55.74 ST31    10.66 ST35   468.86 ST39   548.58 ST41   476.73 ST45   492.18 ST47 1249.62
ST51 1127.23 ST56   252.22 ST57   731.74 ST58   750.68 ST62 1956.62 ST65 1436.95 ST66   263.66 ST84   589.05
ST86   558.52  LT2   536.37  LT5   516.99  LT6   531.66 SN8162645.63 SQ19    11.28 SQ83     0.36 SQ85     0.54
 LQ2    31.72  LQ5    14.67

      CALCULATIONS
 101     3.175  102     2.033  103     0.640            0.000 104A    98.197  105     3.183  106 ********  107     3.307
 160     1.368  108    10.550  109 ********  110     5.209  111   247.551  112     7.736  113   288.614  114   142.481
 115   104.988  116    69.091  117    57.390  118    42.410  119    27.909  120    68.024                0.000 121B     6.790
         0.000 121D    44.283 121E    42.687 121F    80.180  122    62.300  123    83.578  124     2.662  125     0.513
 126     1.435  127     1.740  128    -0.042  129     0.816  130     0.851  131     0.133  132     0.757  133     0.207
 134     0.319  135     0.893  136     0.801  137     1.241  138    -0.088  139     0.654  140  -524.336  141 4293.303
 142 4968.707  143   768.187  144   853.093  145 1022.833  146   166.853  147   143.098  148 7006.249  149 ********
 150   210.597  151   -68.698  152 4726.432  153 1794.668  154 2931.763  155 1904.330  156 8103.690  157 7888.986
 158   102.721  159     3.497  161     0.149

 106    13093.                 109 1568074.
 145    1022.833               148    7006.249
 149   13230.960               152    4726.432
 153    1794.668               154    2931.763
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                                        RUN 187, EVENT 692
                                   ***    H2O2 APU PERFORMANCE    ***
      DATE   2- 5-75                                                                            READING    692
      TIME  11- 4-51                                                                          BAROMETER  13.39 PSIA


      DATA IN ENGINEERING UNITS
RP66   874.71 RP67   550.68 DL68      6.10 DL69      4.65  SP5   873.44   SP7   516.21 DH68      6.06 DH69      4.93
SP18   114.80 SP63     7.72 SP27    549.13 SP58    533.98 SP62     94.85            0.17 SP64      0.17  LP1  3772.09
 LP2    80.58 RT66   489.19 RT67    523.94  ST5    514.52  ST7    666.39 ST16    531.01 ST17    486.01 ST18   590.16
ST19   569.49 ST27    57.68 ST31     10.66 ST35    468.48 ST39    571.88 ST41    475.78 ST45    500.10 ST47  1320.70
ST51  1093.94 ST56   206.89 ST57    729.59 ST58    749.67 ST62   1968.46 ST65   1463.A2 ST66   -502.30 ST84   596.84
ST86   562.25  LT2   537.61  LT5    517.11  LT6    527.27 SN8162692.88 SQ19     11.39 SQ83      0.41 SQ85     0.55
 LQ2    17.32  LQ5   -14.69

      CALCULATIONS
 101     2.226  102     1.472  103     0.661           0.000 104A    52.321  105     4.241  106 9481.236  107     3.349
 160     1.367  108     7.976  109 ********  110     3.699  111   159.503  112     8.280  113  317.080  114    97.211
 115    59.782  116    -3.614  117    60.891  118    37.480  119    -2.266  120    24.536          0.000 121B    7.460
         0.000 121D    44.889 121E    70.857 121F   108.286  122   -11.075  123    84.299  124     1.611  125     0.615
 126     0.914  127     1.311  128    -0.045  129     0.856  130     0.815  131     0.171  132     0.849  133     0.169
 134     0.440  135     0.814  136     0.851  137     2.040  138    -0.093  139     0.706  140 -383.381  141  2757.473
 142  3480.284  143   719.410  144   774.657  145   993.399  146   184.059  147   159.989  148 4596.790  149 ********
 150   156.484  151   -53.677  152 ********  153 ********  154 ********  155  1939.452  156 8570.677  157  7914.807
 158   108.286  159     3.584  161     0.140

 106     9481.                 109 1422959.
 145      993.399              148    4596.790
 149    15565.019              152   -5162.448
 153    -1245.358              154   -3917.090

                                        RUN 187, EVENT 695
                                   ***    H2O2 APU PERFORMANCE    ***
      DATE   2- 5-75                                                                            READING    695
      TIME  11- 5-51                                                                          BAROMETER  13.39 PSIA


      DATA IN ENGINEERING UNITS
RP66   874.51 RP67   551.17 DL68     11.58 DL69      9.26  SP5   870.83   SP7   505.67 DH68     11.58 DH69      9.74
SP18   118.13 SP63    14.16 SP27    547.79 SP58    526.14 SP62    137.86            0.28 SP64      0.28  LP1  3787.09
 LP2    77.62 RT66   488.88 RT67    523.52  ST5    510.39  ST7    680.05 ST16    536.78 ST17    487.45 ST18   577.76
ST19   555.06 ST27    49.64 ST31     10.66 ST35    467.78 ST39    549.63 ST41    475.65 ST45    496.02 ST47  1283.83
ST51  1128.58 ST56   254.02 ST57    730.30 ST58    749.16 ST62   1955.34 ST65   1449.49 ST66   -580.32 ST84   601.61
ST86   566.42  LT2   538.78  LT5    517.11  LT6    533.37 SN8162629.88 SQ19     11.26 SQ83      0.38 SQ85     0.61
 LQ2    31.47  LQ5    14.97

      CALCULATIONS
 101     3.146  102     2.030  103     0.645           0.000 104A    97.616  105     3.181  106 ********  107     3.316
 160     1.368  108    11.055  109 ********  110     5.176  111   248.824  112     8.549  113  333.355  114   137.488
 115   105.460  116    76.034  117    55.121  118    42.383  119    30.557  120    68.118          0.000 121B    7.843
         0.000 121D    39.872 121E    37.268 121F    69.297  122    68.191  123    83.321  124     2.526  125     0.620
 126     1.433  127     1.713  128    -0.036  129     0.810  130     0.848  131     0.137  132     0.744  133     0.206
 134     0.333  135     0.807  136     0.826  137     2.128  138    -0.085  139     0.771  140 -449.145  141  4284.787
 142  4911.438  143   783.620  144   867.858  145  1062.782  146   217.923  147   181.663  148 6917.626  149 ********
 150   207.688  151   -82.667  152 ********  153  2030.265  154 ********  155  1911.026  156 8556.714  157  7892.127
 158   108.420  159     4.109  161     0.141

 106    13070.                 109 1586124.
 145     1062.782              148    6917.626
 149    22691.102              152   -4363.793
 153     2030.265              154   -6394.059

                                        RUN 187, EVENT 698
                                   ***    H2O2 APU PERFORMANCE    ***
      DATE   2- 5-75                                                                            READING    698
      TIME  11- 6-51                                                                          BAROMETER  13.39 PSIA


      DATA IN ENGINEERING UNITS
RP66   874.71 RP67   551.50 DL68      6.05 DL69      4.54  SP5   872.84   SP7   523.91 DH68      6.23 DH69      4.85
SP18   114.18 SP63     7.93 SP27    550.33 SP58    535.47 SP62     96.85            0.18 SP64      0.18  LP1  3772.09
 LP2    81.56 RT66   489.56 RT67    523.16  ST5    508.80  ST7    680.79 ST16    542.64 ST17    494.08 ST18   593.23
ST19   572.05 ST27    53.16 ST31     10.66 ST35    467.65 ST39    573.79 ST41    474.92 ST45    505.13 ST47  1334.10
ST51  1093.71 ST56   205.85 ST57    725.89 ST58    748.86 ST62   1962.38 ST65   1473.45 ST66   -104.15 ST84   605.31
ST86   568.58  LT2   284.04  LT5    517.41  LT6    528.34 SN8162771.63 SQ19     11.38 SQ83      0.44 SQ85     0.63
 LQ2    15.62  LQ5    14.62

      CALCULATIONS
 101     2.204  102     1.465  103     0.664           0.000 104A    52.300  105     4.210  106 9436.679  107     3.356
 160     1.366  108     8.116  109 ********  110     3.670  111   158.575  112     9.178  113  348.541  114    93.267
 115    60.500  116    58.076  117    58.793  118    38.152  119    36.623  120    24.508          0.000 121B    8.200
         0.000 121D    40.967 121E    10.625 121F    43.392  122    49.875  123    95.770  124     1.565  125     0.639
 126     0.913  127     1.291  128    -0.040  129     0.853  130     0.811  131     0.176  132     0.844  133     0.168
 134     0.449  135     0.712  136     0.856  137     1.629  138    -0.105  139     0.792  140 -343.119  141  2755.866
 142  3439.648  143   735.584  144   787.021  145  1159.913  146   228.915  147   192.906  148 4512.463  149 ********
 150   177.154  151   -60.501  152   528.475  153  1332.690  154  -804.215  155  1944.584  156 8797.862  157  7917.626
 158   111.117  159     3.997  161     0.136

 106     9436.                 109 1425838.
 145     1159.913              148    4512.463
 149    12370.594              152     528.475
 153     1332.690              154    -804.215
```

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OF POOR QUALITY

RUN 187, EVENT 705

*** H2O2 APU PERFORMANCE ***

DATE 2- 5-75
TIME 11- 8-51

READING 705
BAROMETER 13.39 PSIA

DATA IN ENGINEERING UNITS

RP66	873.11	RP67	558.69	DL68	13.75	DL69	13.76	SP5	860.01	SP7	504.45	DH68	31.49	DH69	25.02
SP18	123.81	SP63	30.83	SP27	545.65	SP58	509.39	SP62	251.57		0.59	SP64	0.59	LP1	3746.08
LP2	74.81	RT66	488.82	RT67	521.55	ST5	503.66	ST7	693.90	ST16	553.56	ST17	500.54	ST18	584.34
ST19	553.74	ST27	46.40	ST31	10.66	ST35	466.76	ST39	536.55	ST41	475.84	ST45	494.29	ST47	1205.51
ST51	1139.42	ST56	333.36	ST57	733.27	ST58	748.55	ST62	1950.86	ST65	1419.05	ST66	-456.73	ST84	610.71
ST86	576.69	LT2	553.04	LT5	517.05	LT6	546.20	SN8	162598.38	SQ19	11.20	SO83	0.43	SO85	0.74
LQ2	74.22	LQ5	14.72												

CALCULATIONS

101	5.160	102	3.304	103	0.640		0.000	104A	196.924	105	2.578	106	********	107	3.306
160	1.368	108	18.939	109	********	110	8.464	111	467.745	112	9.958	113	375.982	114	236.720
115	205.771	116	121.661	117	50.502	118	43.992	119	26.010	120	158.984		0.000	121B	8.846
	0.000	121D	39.796	121E	92.956	121F	123.906	122	112.814	123	82.201	124	4.680	125	0.479
126	2.599	127	2.560	128	-0.032	129	0.737	130	0.867	131	0.115	132	0.593	133	0.260
134	0.237	135	0.682	136	0.769	137	2.028	138	-0.066	139	0.828	140	-675.460	141	7218.155
142	8036.069	143	1055.609	144	1214.994	145	1417.880	146	323.616	147	230.078	148	********	149	********
150	275.980	151	-150.863	152	********	153	3579.620	154	********	155	1902.123	156	9167.592	157	7884.325
158	116.276	159	4.785	161	0.131										

106	21272.	109	1823605.
145	1417.880	148	11599.580
149	34349.929	152	-4671.795
153	3579.620	154	-8251.417

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2. Harris, E. and staff, Design of H_2-O_2 Space Shuttle APU, Volume 2- Appendixes. AiResearch Report 74-9874-2, also NASA CR-134485, January 1974.

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