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Test Report for NASA MSFC Support of the Linear Aerospike SR–71 Experiment (LASRE)

S.K. Elam
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February 2000

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LIST OF ACRONYMS

BLC	boundary layer coolant
$CaCo_3$	calcium carbonate
CFD	computational fluid dynamics
DFRC	Dryden Flight Research Center
ECF	environmental correction factor
F/M	flow meter
F.S.	factor of safety
FRR	flight readiness review
GHe	gaseous helium
GH_2	gaseous hydrogen
H_2O	water
LASRE	Linear Aerospike SR–71 Experiment
LMA	Lockheed Martin Astronautics
LMSW	Lockheed Martin Skunkworks
LOX	liquid oxygen
LN_2	liquid nitrogen
MEOP	maximum expected operating pressure
MR	mixture ratio
MSFC	Marshall Space Flight Center
NiCrAlY	nickel, chromium, aluminum, yttrium
OFHC	oxygen-free high conductivity
RLV	reusable launch vehicle
SSFL	Santa Susanna Field Laboratory
TEA	triethylaluminum
TEB	triethylboron
ZrO_2	zirconium oxide

NOMENCLATURE

A	flow area
A_c	chamber area
A_c/A_t	chamber's contraction ratio
A_t	throat area
C^*	characteristic velocity
C_d	discharge coefficient
D	diameter
g_c	gravitational constant
h_f	enthalpy of fuel
$h_{\mathrm{H2,std}}$	standard enthalpy of hydrogen
$h_{\mathrm{O_2}}$	enthalpy of oxygen
h_{o}	enthalpy of oxidizer
$h_{\mathrm{O2,std}}$	standard enthalpy of oxygen
$\dot{m}$	flow rate
$\dot{m}_f$	fuel flow rate
$\dot{m}_o$	oxidizer flow rate
P	pressure
P_c	chamber pressure
$P_{c,ns}$	nozzle stagnation pressure
P_t	total pressure
$\dot{Q}$	heating rate
R	resistance
$\mathbf{R}$	universal gas constant
T	temperature

NOMENCLATURE (Continued)

$T_{c,ns}$	nozzle stagnation temperature
Z	compressibility function
ΔP	pressure change
ΔT	temperature change
γ	specific heat ratio
ρ	density

TECHNICAL MEMORANDUM

TEST REPORT FOR NASA MSFC SUPPORT OF THE LINEAR AEROSPIKE SR–71 EXPERIMENT (LASRE)

1. INTRODUCTION AND OBJECTIVES

In support of the Reusable Launch Vehicle (RLV) X–33 program, testing of the Linear Aerospike SR–71 Experiment (LASRE) was conducted at NASA's Dryden Flight Research Center (DFRC) and the Air Force's Phillips Laboratory during March 1996–November 1998. The objective of this program was to operate a linear aerospike engine at various speeds and altitudes to determine how slipstreams affect the performance of the engine.

Slipstream effects could degrade an aerospike engine's performance as air flows over the vehicle's surface and interacts with the exhaust plume. Cold flow wind tunnel testing suggested such effects might reduce engine performance by 6 percent. By mounting and testing the LASRE engine on the back of an SR–71, performance data at various speeds and altitudes could be achieved to help understand the actual magnitude of slipstream effects.

Rocketdyne Division of Boeing North American fabricated the LASRE engine and delivered it to Lockheed Martin Skunkworks (LMSW). LMSW integrated the engine into a structural assembly that was designed and fabricated to fit on the SR–71 aircraft. This structural assembly also housed the propellant feed systems, which were designed and fabricated by Lockheed Martin Astronautics (LMA).

The final test plan concentrated on operating the engine at chamber pressures around 200 psi and mixture ratios of ≈6 for 3 sec. In flight, these conditions were planned to be performed at altitudes ranging from 30,000 to 50,000 ft and Mach numbers ranging from 0.9 to 1.5.

DFRC requested that NASA's Marshall Space Flight Center (MSFC) support this program by providing technical expertise in liquid propulsion testing. This report presents details of the technical support that MSFC provided throughout the test program.

2. LASRE ENGINE HARDWARE

The LASRE engine shown in figure 1 created the aerospike configuration with four individual thrusters on each side. Its overall size was ≈10 percent of the engine actually being designed for the RLV's X–33 vehicle, which will use two aerospike engines with 10 thrusters per side. Each thruster was supplied with liquid oxygen (LOX) and gaseous hydrogen (GH_2) for propellants and deionized water for coolant. On each side of the engine, the combustion gases exiting the thrusters expanded along the curved, water-cooled ramps of the nozzle assembly. Water-cooled fences created the upper and lower boundaries of the engine's structure. These fences helped protect the uncooled surfaces surrounding the engine assembly by retaining the exhaust gases.

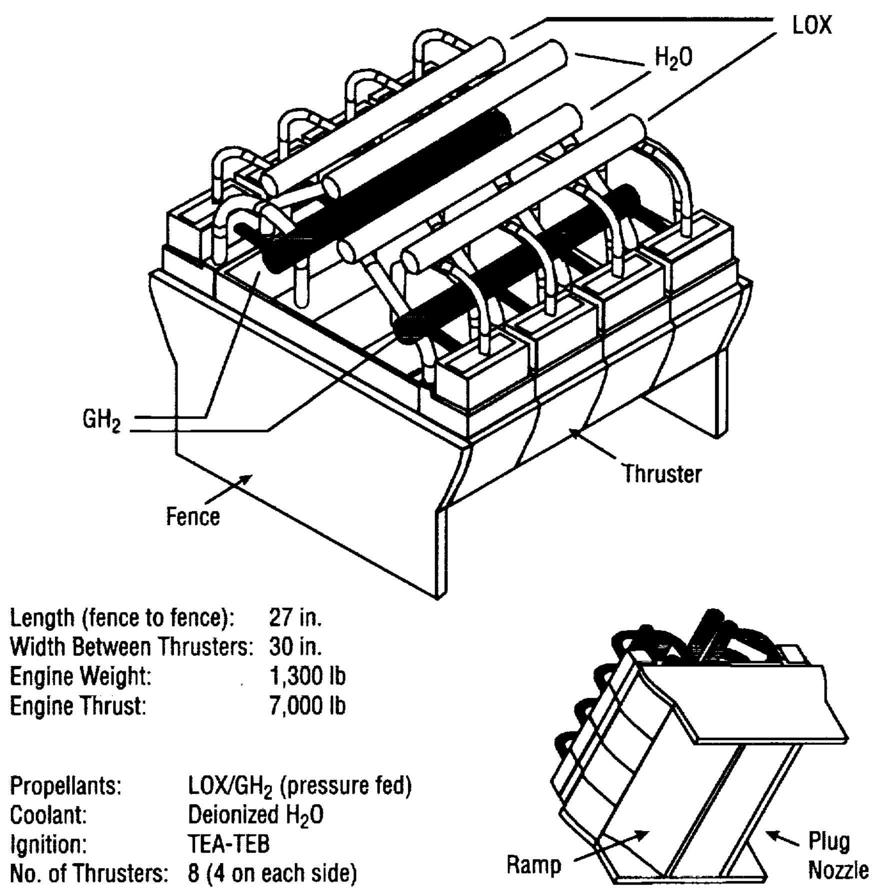


Figure 1. LASRE engine hardware.

2.1 Thruster Assembly

Figures 2 and 3 depict different views of the thruster design. Each thruster assembly included an injector and chamber designed for LOX/GH_2 combustion. LOX was supplied through the back of the injector into the LOX manifold while GH_2 was supplied through the side into the fuel manifold. Each chamber was cooled with deionized water. The hypergolic fluid triethylaluminum (TEA)-triethylboron (TEB) (TEA-TEB) was provided for ignition. It was injected through a port in the side of each chamber for ignition with LOX. An additional port in each chamber's side wall was used to measure the internal chamber pressure, P_c, at the injector end.

Twenty-five circumferential coolant hole passages distributed the water along the chamber wall. As shown in figure 2, the water entered each chamber in the bottom inlet manifold before being distributed to the coolant passages. (The inset in figure 2 illustrates the direction of the water flow in each passage.) The diameter of each coolant hole passage was 3/32 in., while each manifold was 1-in. in diameter. Common manifolding of the passages prevented local, individual coolant temperature and pressure measurements. Inlet and exit lines were brazed to the chamber to supply the water coolant.

Figure 2 also shows the overall dimensions of the thruster assembly. The rectangular cross section of the chamber measured 1.5 in. × 5 in. at the injector end, narrowing to 0.357 in. × 5 in. at the throat.

The chamber was fabricated with NARloy-Z (a copper alloy). To provide some additional thermal protection, the hot wall of each chamber was coated with zirconium oxide (ZrO_2) in gradiated layers with NiCrAlY (an alloy of nickel, chromium, aluminum and yttrium). The three-layer coating included equal layers of NiCrAlY along the NARloy-Z surface, followed by 50-percent NiCrAlY/50-percent ZrO_2, and finally ZrO_2, providing a total coating thickness of ≈0.009 in. The ZrO_2 provided the thermal barrier, while the undercoatings provided compliant layers with the NARloy-Z surface. All coatings were applied in atmosphere. (Though Rocketdyne's original analysis suggested plenty of cooling margin without a thermal coating, it was applied anyway for additional margin.)

Figure 3 shows a profile of the injector, which was brazed to each chamber to complete the thruster assembly. The faceplate design included 48 coaxial elements. Each element provided LOX through the center post (inner diameter ≈0.06 in.) and fuel through the surrounding annulus (fuel gap ≈0.014 in.). Boundary layer coolant (BLC) holes surrounded the perimeter of the faceplate to direct fuel film coolant on the chamber hot wall to help reduce local heating rates. Each of the 68 BLC holes measured ≈0.030 in. in diameter.

The entire injector assembly was fabricated with stainless steel (CRES 304L) materials, except for the faceplate which was made with oxygen-free high conductivity (OFHC) copper. The fabrication process included several braze operations. Each LOX post was brazed into the injector body and resulting joints were visually inspected. Separate braze operations were used to attach the injector faceplate and manifold closeout structures. Joints were ultrasonically inspected, followed by proof and leak tests before hardware delivery.

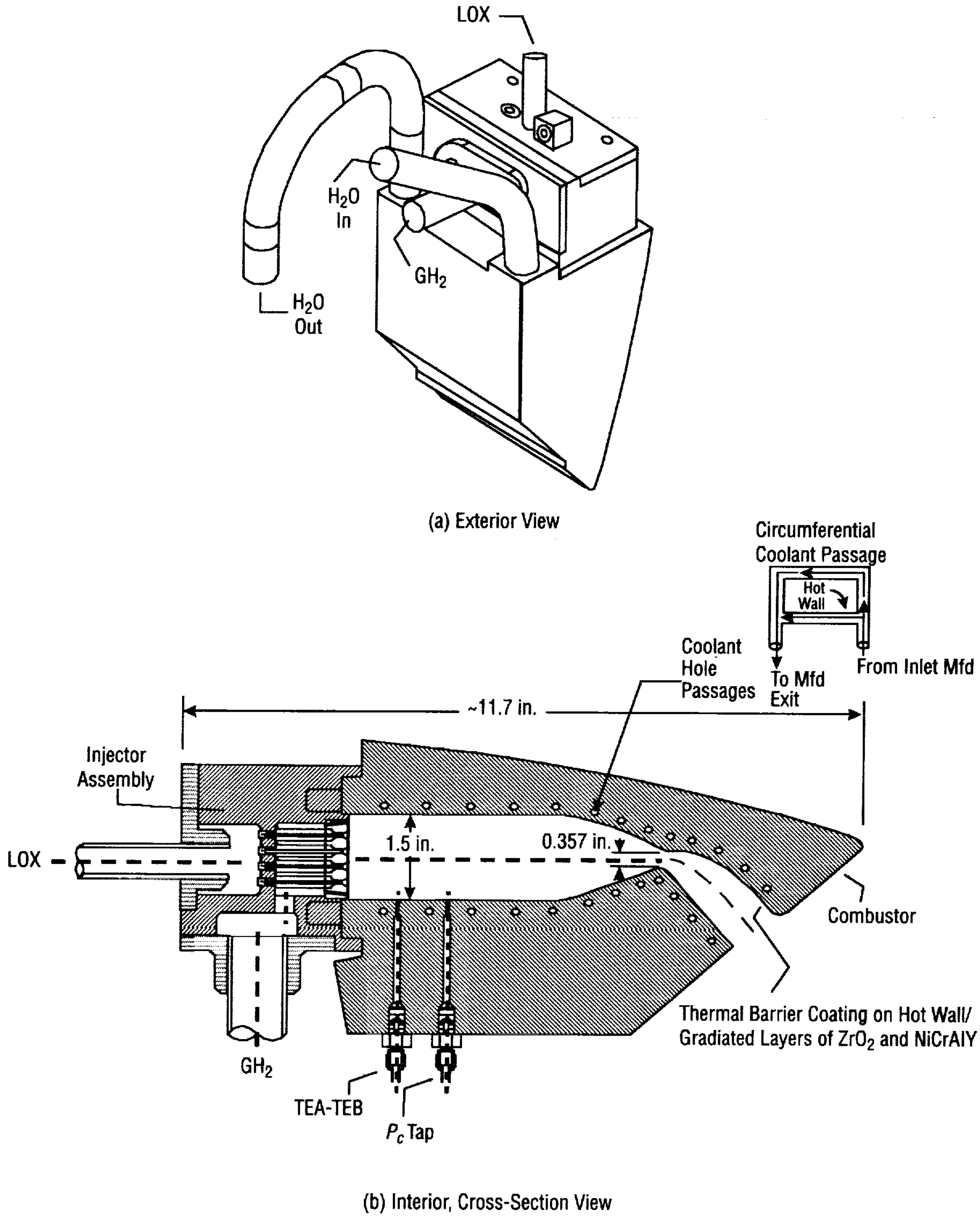


Figure 2. Thruster design: (a) exterior and (b) interior views.

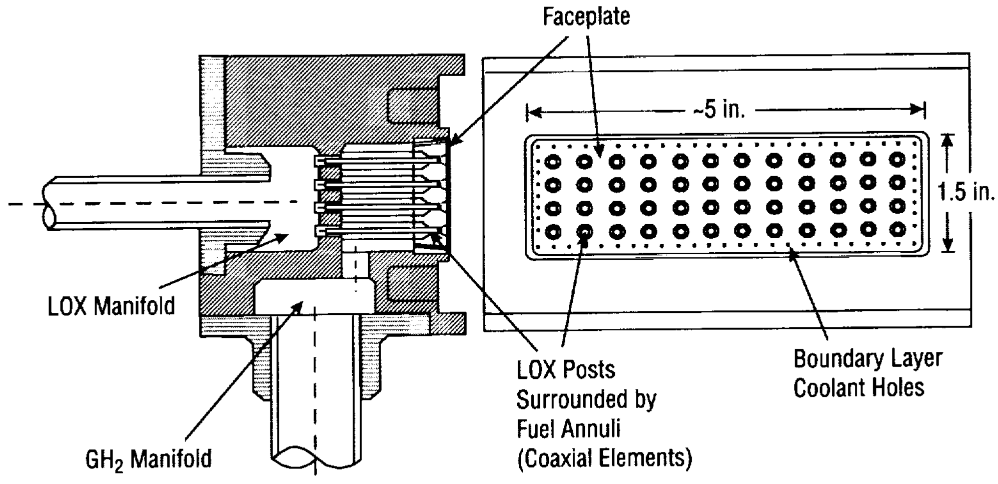


Figure 3. LASRE injector.

2.2 Single Thruster Testing

Rocketdyne fabricated nine thruster assemblies, and eight were used for the LASRE engine. The additional thruster was tested at Rocketdyne's Santa Susanna Field Laboratory (SSFL) to verify the design and recommended operating sequence. Each thruster was designed to operate at chamber pressures ranging from 200–300 psia, as originally required by the LASRE program. Objectives of the single thruster testing included operating the thruster within this range at various mixture ratio levels. In addition, a total accumulated duration of 180 sec was planned to provide exposure for 1.5 times the total duration originally planned for the LASRE engine (120 sec).

Results at SSFL compiled a total of 112 sec on the thruster within the desired operating conditions. Unfortunately, a failure occurred on the hot wall of the chamber liner during the 12th mainstage test, ending the program before the desired total duration was achieved. The failure was primarily caused by impurities in the facility water used to cool the thruster. A similar failure was not expected for the LASRE engine because deionized water would be used to cool the entire assembly.

However, the failure investigation provided an additional, more thorough review of the thruster design. Additional analytical results showed the thermal margin for cooling the chamber was much lower than results implied by the original analyses. Acceptable margin was only available for operating the thruster design at a chamber pressure around 200 psia, unless a higher coolant flow rate could be provided for the LASRE system. Water blowdowns of the LASRE engine eventually showed that additional coolant was not available. So, to be conservative, the test conditions for LASRE were changed to concentrate on testing only at chamber pressures of 200 psia (at least until additional confidence in the hardware could be achieved with successful hot-fire testing in flight).

Appendix A provides further details of this single thruster test program and the failure investigation.

2.3 Nozzle Assembly

The nozzle assembly shown in figure 1 directed the combustion gases exiting the thrusters, allowing them to expand along the curved ramps positioned downstream. This nozzle assembly was also cooled with deionized water. Its inlet manifolds received the coolant exiting the thrusters and directed it to coolant passages within the ramps. Outlet manifolds collected the coolant exiting the ramps and further distributed it to the fences attached to the upper and lower portions of the nozzle assembly. Water from the fences was directed to a single coolant line exiting the engine. The ramps and fences were fabricated from copper with ZrO_2 coatings applied to their surfaces for thermal protection. The engine frame and all plumbing in the assembly were fabricated with stainless steel (CRES 321).

Appendix B provides additional details on the design limitations of the engine hardware.

3. PROPELLANT/COOLANT SUPPLY SYSTEMS

Figure 4 illustrates the complete LASRE flight test hardware assembly, known as the pod. This assembly consisted of several structures identified as the canoe, kayak, reflection plane, and model.

The hydrogen and water systems, along with their associated helium tanks, were housed in the canoe, which was mounted directly to the SR–71 upper fuselage. The canoe also contained the controller used to signal all the systems during operation. The LOX and TEA-TEB systems and their helium tanks were contained within the model. The actual engine assembly was mounted into the aft end of the model, which was connected to a force balance for measuring forces in flight. The contour of the model represented a half-span lifting body shape, similar to the X–33 vehicle design. The kayak positioned above the canoe created the incidence angle of the model, and a flat plate mounted atop the kayak provided a reflection plane downstream of the engine assembly. The contained areas of the pod were purged with nitrogen to help safeguard the enclosures if excessive internal or external leaks resulted.

Figure 5 shows simplified schematics of the propellant and coolant supply systems. Appendix C provides additional information on these systems.

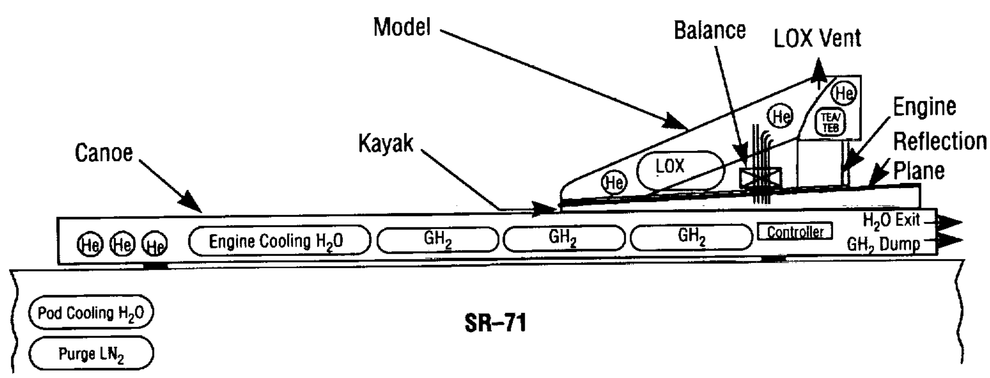
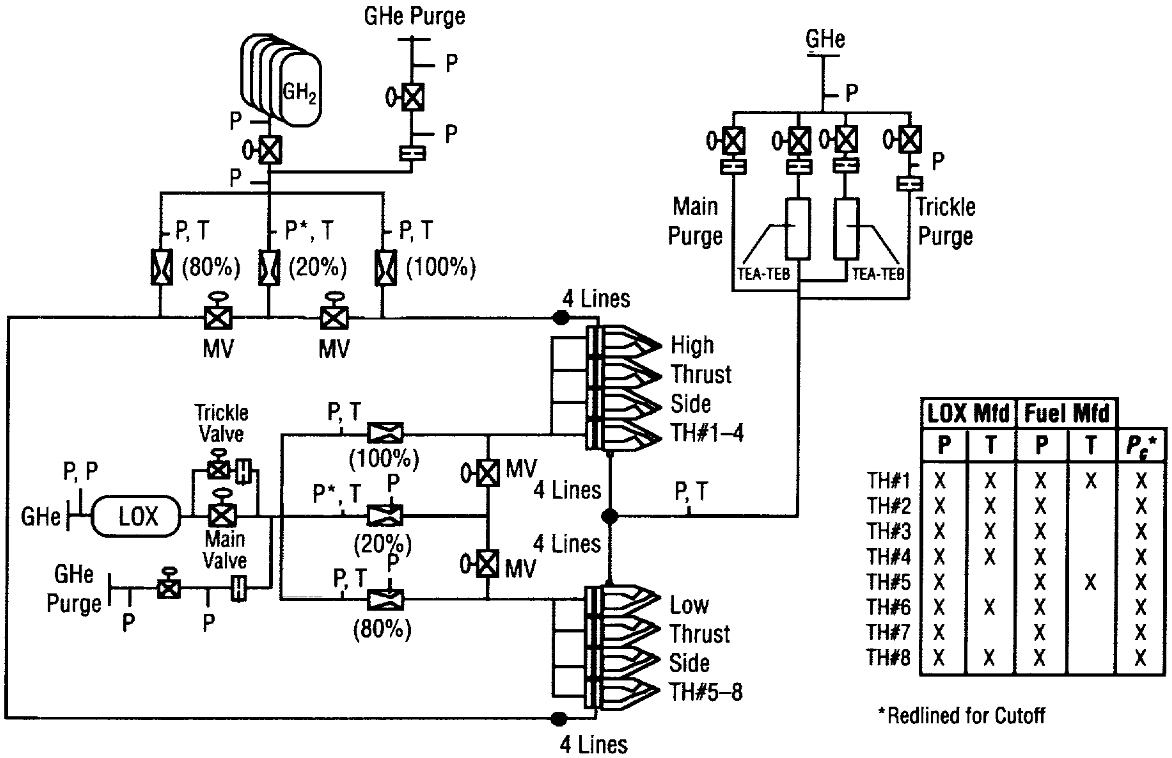
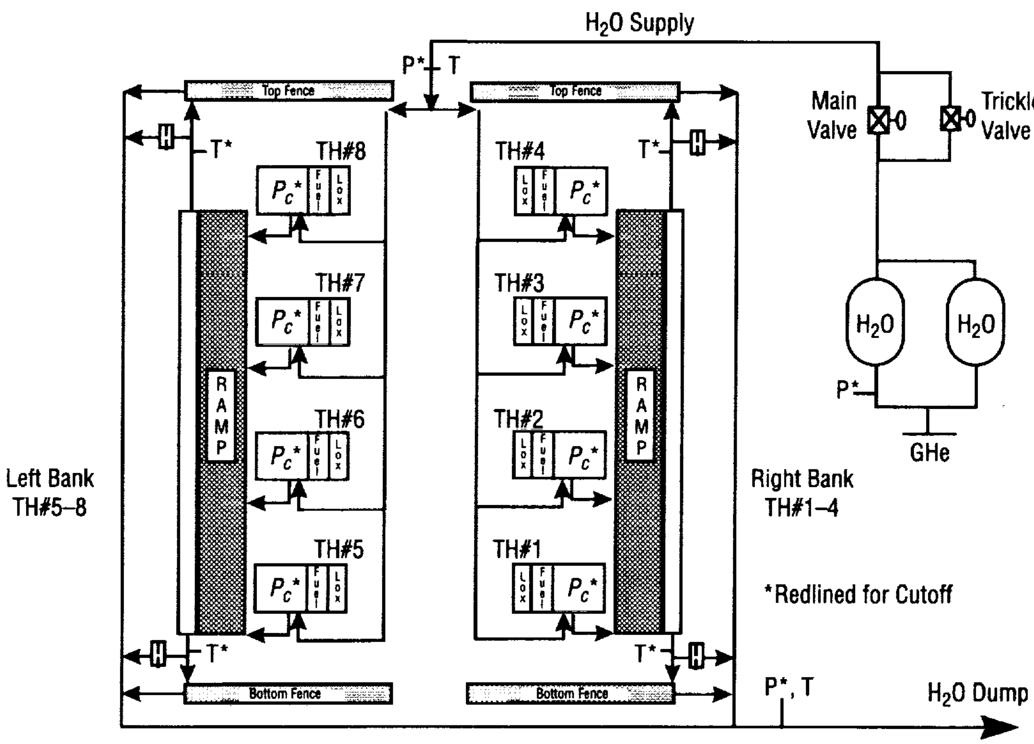


Figure 4. LASRE pod assembly.



	LOX Mfd		Fuel Mfd		
	P	T	P	T	P_c*
TH#1	X	X	X	X	X
TH#2	X	X	X		X
TH#3	X	X	X		X
TH#4	X	X	X		X
TH#5	X		X	X	X
TH#6	X	X	X		X
TH#7	X		X		X
TH#8	X	X	X		X

(a) Propellants



(b) Coolants

Figure 5. LASRE supply systems for (a) propellants and (b) coolant.

3.1 LOX Supply System

LOX was supplied from a single tank positioned upstream of two supply valves. The trickle valve allowed a small, initial flow rate of LOX to properly chill the lines and hardware at the start of the test. The main valve provided flow during the ignition and mainstage phases. Gaseous helium (GHe) was provided to pressurize the tank and properly purge the LOX system.

Three cavitating venturies were used to control the LOX flow rate to the engine. Their size and position allowed the engine to be throttled, if desired. Original test plans included thrust vectored burns where one side of the engine would be operated at 120 percent of the nominal chamber pressure and the other side would be operated at 80 percent. The venturies were sized to provide 100, 80, and 20 percent of the nominal flow rate.

Two manual valves were positioned downstream of the 20-percent venturi, allowing flow to either bank of thrusters to create the desired throttled flow rate. For all the tests actually performed in this program, the manual valve to thrusters 1–4 was closed and the manual valve to thrusters 5–8 remained open. Thrusters 1–4 received the flow provided by the 100-percent venturi, and thrusters 5–8 received the combined flow provided by the 80- and 20-percent venturies.

3.2 Fuel Supply System

GH_2 was supplied for fuel from five tanks. A regulating valve was used to control the fuel supply based on the pressure required at the venturi inlets. Three sonic venturies and two manual control valves were arranged similar to the LOX system to provide appropriately throttled flow rates to each side of the engine. GHe provided the necessary system purge.

The manual valves downstream of the 20-percent venturi were operated in the same configuration as the LOX system. The manual valve to thrusters 1–4 remained closed, while the valve to thrusters 5–8 was opened. Therefore, flow from only the 100-percent venturi was directed to thrusters 1–4, and the combined flow from the 20- and 80-percent venturies was directed to thrusters 5–8.

3.3 TEA-TEB Supply System

Two canisters of the hypergol TEA-TEB were available, since original test plans included two burns per test. Each canister was isolated from the GHe pressurant by a control valve. With the control valve opened, the pressure supplied to the respective canister ruptured the internal burst disk, allowing TEA-TEB to flow to each thruster for ignition with LOX. The continuous GHe flow provided a purge of this system after expelling the TEA-TEB. Additional valves allowed this system to be purged even when the canister supply valves remained closed. In addition, a constant trickle purge was kept on the TEA-TEB system at all times to ensure the cleanliness of the lines and prevent the small TEA-TEB ports in each thruster from getting blocked.

3.4 Water Coolant Supply System

Deionized water was supplied from two tanks, pressurized with GHe. A small supply valve initiated water flow to the hardware with a reduced flow rate to prime the system and prevent water hammer effects. The main supply valve provided the full coolant flow rate to the hardware during ignition and mainstage phases of the test. Figure 5(b) shows the coolant was provided to each individual thruster to properly cool the walls of the chamber. The exit flow from each thruster was collected in the inlet manifolds of the nozzle assembly where it was directed to cool each ramp. Flow exiting the ramps was also used to cool the fences surrounding the assembly, and finally all coolant flow was collected and exhausted out a common exit line from the engine.

(In initial ground testing, an orifice and a flow meter were positioned in the exit line (downstream of the exit line pressure transducer) to help characterize the flow rate available for cooling the engine. To provide as much coolant flow as possible, the orifice was eventually removed to limit the resistance in the water system. The flow meter remained for additional tests, but it was eventually removed as well.)

4. INSTRUMENTATION

Pressure transducers and thermocouples were placed throughout the supply systems and engine to provide appropriate data. Figure 5 illustrates the location of specific pressure (*P*) and temperature (*T*) measurements. Redlined parameters are highlighted with an "*." Appendix D provides the complete engine and supply systems instrumentation list for this program.

Each thruster included a port for measuring chamber pressure results at the injector end. In addition, pressures were measured in each thruster's LOX and fuel manifolds. Thermocouples could not be supplied for each manifold, but temperatures were measured in as many locations as possible in each bank of thrusters. Thrusters 1–4 were called the "high" thrust side of the engine, since they were capable of providing the highest chamber pressure condition with 120-percent of the propellant flow available. This side of the engine was instrumented with a thermocouple in each LOX manifold and the fuel manifold of thruster No. 1. The "low" thrust side of the engine with thrusters 5–8 included LOX manifold temperature measurements in thrusters Nos. 6 and 8, while a fuel manifold temperature was measured only in thruster No. 5. It was important to include at least one fuel manifold temperature measurement on each side of the engine to help detect any backflow of propellants during engine operation and to help investigate any anomalies.

A pressure and temperature measurement were located upstream of each venturi to provide data for calculating propellant flow rates. In addition, to help verify cavitation in the 20- and 80-percent venturies in the LOX system, throat pressure measurements were available.

5. OPERATING SEQUENCE

While appendix E provides a more detailed sequence, figure 6 provides a simplified sequence to describe the ignition, mainstage, and shutdown operations. Various sequence changes were made during the course of this program, but only the final sequence used for the successful ground hot-fires is provided in this report. A single control panel with limited switches was used to signal the integrated controller and perform each test. After completing the ground configuration tests at Phillips Laboratory, this control panel was installed in the aft cockpit of the aircraft.

The LOX and TEA-TEB systems were initially purged with GHe. The trickle flow of LOX was provided for 8 sec to properly chill the lines and hardware. Results provided a cold system that prevented the main flow of LOX from vaporizing, so good quality LOX was available for ignition and mainstage operation. Just before initiating the main flow of LOX, the trickle flow of water was started to properly prime the system, followed by the main flow of water to properly cool the thrusters before combustion. Soon after the main flow of LOX was provided, the TEA-TEB was supplied to provide ignition in each thruster. During this ignition phase, a purge was provided to the fuel side of each injector. The chamber pressure in each thruster was checked and if each showed at least 15 psig, ignition was confirmed and the fuel flow was initiated.

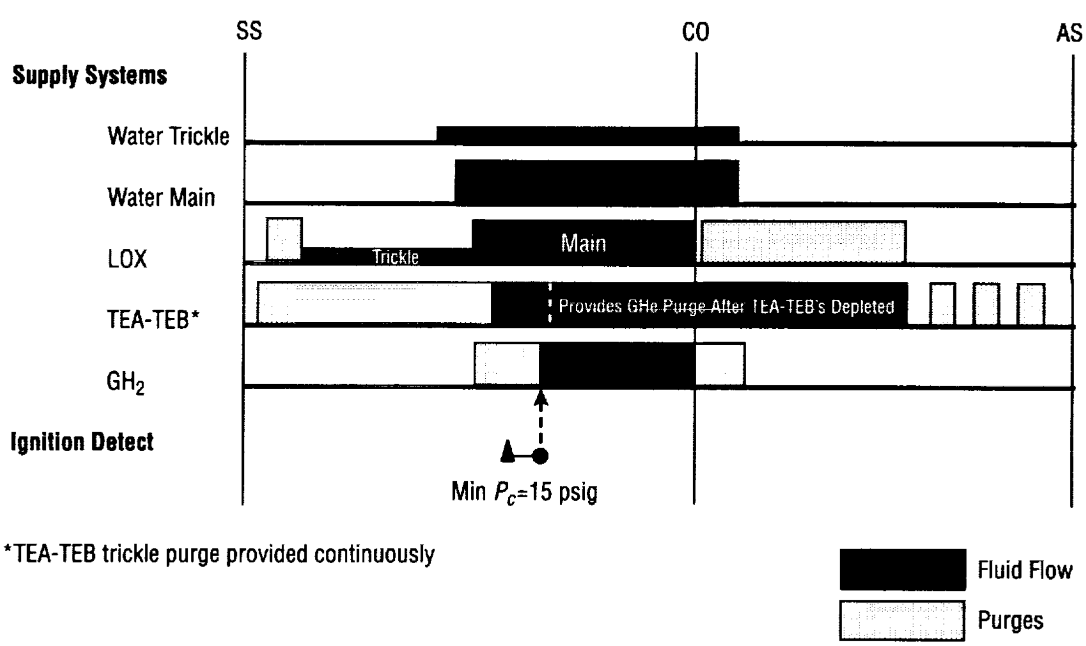


Figure 6. Simplified LASRE sequence.

Fuel was provided for only 3 sec before cutoff occurred. LOX and fuel supply valves were both closed at cutoff, and purges were supplied to each system. The GHe used to pressurize the TEA-TEB canister provided a continuous, proper purge after the hypergol was completely expelled. After cutoff, the water flow continued as the purges pushed residual propellants out the engine. When the LOX and TEA-TEB purges were completed, the TEA-TEB system was provided with three "puff" purges to help clear out any accumulated TEA-TEB residue. (Note: Although it is not shown, a continuous, low-level purge was also provided through the TEA-TEB system to further ensure cleanliness.)

While this sequence was similar to component testing operations at MSFC, there were some slight differences due to the limitations of the LASRE engine system. Specifically, this system was not capable of providing a positive purge on the fuel side of the injector during the ignition phase. However, even though ignition products were allowed to flow into the fuel side of the system, the fuel flow was preceded by GHe flow that appeared to properly clear the fuel manifolds of the ignition products before hydrogen reached this area of the hardware. Therefore, all mainstage combustion appeared to occur only in the combustion chamber, as desired. Fuel manifold pressures and temperatures did not indicate any sustained internal burning in this area of the injectors, so the sequence appeared to be sufficient for the operation of this system. (A higher purge to provide positive pressure on the fuel side was not possible due to the limited amount of GHe available for the LASRE system.) Also, the shutdown sequence did not ensure a fuel-rich shutdown to protect the walls of the chambers from exposure to LOX after a hot-fire. However, Rocketdyne's testing on the single thruster used a LOX-rich shutdown and demonstrated the hardware's integrity to such exposure. Hardware inspections on each chamber did not reveal any hot spots or liner degradation that could be attributed to a LOX-rich environment.

Appropriate redlines were active during this sequence to ensure the test was properly terminated if anomalies occurred. Table 1 further describes the parameters used for redline values in the supply systems and the engine.

Table 1. Redlined parameters used for cutoff.

Redline Parameter	Reason for Cutoff
Maximum water tank pressure	Prevent overpressurizing the water tanks
Maximum water inlet pressure	Could indicate frozen coolant or engine obstruction; redundant indication of overpressured water tanks
Minimum water inlet pressure	Insufficient coolant flow to the engine
Maximum water exit pressure	Significant change in engine/line resistance
Minimum water exit pressure	Pressure loss in engine due to failure or frozen coolant
Maximum water ramp temperature	Engine overheating
Maximum LOX venturi inlet pressure	Prevent high P_c and/or high engine mixture ratio
Maximum GH_2 venturi inlet pressure	Prevent high P_c
Minimum GH_2 venturi inlet pressure	Prevent low P_c and/or high engine mixture ratio
Minimum P_c	Avoid unstable operating region; indicates engine failure/loss of pressure in engine; no ignition
Maximum P_c	Prevent overpressurizing/overheating engine

The autosafe sequences after shutdown were used to remove residual fluids from the systems after the completed tests. The fuel system was "autosafed" first to remove the fuel while the LOX system was isolated. Water was also expelled prior to the LOX autosafe sequence. Original sequences did not include an autosafe of the water system. However, when the stagnant water in the engine began to freeze when exposed to the cold temperatures of the LOX autosafe procedure, the water autosafe sequence was added to remove this water before expelling LOX. Finally, the LOX autosafe was performed to remove any oxidizer remaining in the system. These sequences were part of the procedures performed before landing the aircraft to minimize the propellants on board.

6. TEST SUMMARY

Ground configuration testing at Phillips Laboratory was performed from March 1996 to April 1997. Tests in this series included GRUN0019–37. Flight configuration testing was performed at DFRC from September 1997 to October 1998. This test series included additional ground tests, GRUN0038–63, as well as flight tests, FLT0047–51.

Trends in the test results were evaluated by reviewing transient and steady-state data of each system. The resulting values and trends were compared between each test to check for appropriate and consistent responses. Transient data represented the actual response of a specific parameter over a period of time. Steady-state data were evaluated at a specific time slice during the test. This time slice was usually taken near the end of the main flow of propellants, after all instrumentation responses had enough time to stabilize. Unless specific operating sequence or hardware changes were made, transient and steady-state results were expected to remain consistent between tests. Inconsistent data were evaluated further to immediately identify possible anomalies in the hardware or operating system. Resulting values were also compared to the redline values to make sure cutoff limits were appropriately set.

Appendix F provides a summary of most of the steady-state data obtained throughout this test program. Some of the transient data can be found in appendices G–L.

6.1 Ground Configuration Testing

To verify the performance and operation of the propellant system and the engine, numerous blowdowns and cold flows were performed at Phillips Laboratory prior to hot-fire testing. This ground testing was performed so the entire LASRE system could be checked out properly before installing it on the SR–71.

Original test plans included two burns per test, so some of these checkout tests included single and double blows to properly evaluate the capabilities of the systems. Eventually, system limitations identified in the cold flows changed the test plans to include only single blows.

After the systems were thoroughly checked with the cold flows, ignition tests were performed, followed by two successful hot-fire tests. Appendix F includes the steady-state data for these ground tests.

6.1.1 Water System Tests

Blowdowns of the water system were performed to identify the flow resistances and determine the maximum flow rate available for cooling the engine hardware. The hardware was originally designed to operate with plenty of thermal margin if at least 40 lb_m/sec were supplied to the engine. However, thermal analyses performed after the single thruster failure at SSFL recommended a higher coolant flow rate be provided to ensure adequate thermal margins when testing at chamber pressures much higher than 200 psia (see app. A).

Initial water system blowdowns attempted to attain higher flow rates by operating the water tanks at their maximum allowable pressures. Unfortunately, the flow resistances throughout the coolant system were much higher than predicted. Even an orifice, originally included in the exit line downstream of the engine to regulate the flow rate, was eventually removed to eliminate as much resistance as possible. A flow meter was available in the exit line to measure resulting flow rates without the orifice in place. (This flow meter was eventually removed, and when it was no longer available, coolant flow rates were determined by scaling the pressure drops observed in each test.)

Even when using the maximum water supply pressure, only 40 lb_m/sec was available for cooling the thrusters. Based on these results, the test conditions of 250 and 300 psia included in the original test plans were eliminated, and subsequent blowdowns and cold-flow testing concentrated on preparing for hot-fire conditions at 200 psia.

Final configuration of the water system provided water inlet pressures to the engine around 600 psia. With 40 lb_m/sec provided for the total coolant flow rate, a pressure drop of $\approx$400 psi resulted through the engine, creating a water exit pressure of $\approx$200 psia. Since the system results were expected to remain constant unless anomalies were experienced, the redlines were set relative to this data. The redlined values set to identify anomalies in the water system and initiate cutoff are provided in table 2.

During the colder months at Phillips Laboratory, ambient temperatures were cool enough to allow freezing in the water system. The freezing was first apparent during the LOX autosafe sequence when stagnant, residual water in the engine froze due to the resulting cold hardware temperatures. The water autosafe sequence was added to remove residual water from the assembly prior to conducting the LOX autosafe. (Since the water was removed with GHe pressurant, the flow meter originally in the exit line was removed so its blades would not be damaged from overspinning when exposed to the high GHe flow that followed the water.)

However, additional freezing continued to be observed at the start of each test. In addition to further changes in the water autosafe sequence, modifications were also made to the start sequence. It appeared that in the original sequence, the LOX trickle flow was enough to freeze residual water (when not successfully removed by the water autosafe sequence) and/or the water trickle flow. So, the sequence was revised to delay the start of the water trickle flow to limit the amount of exposure to the cold system temperatures prior to starting the main water flow before the ignition and mainstage phases. Eventually, the test plans changed to perform only single blows, which helped reduce concerns about freezing residual water between blows.

While appendix F includes steady-state data for the water system, appendix G provides further details and analysis of the water system test results.

Table 2. Redlined values used for water system.

	Redline Value (psia)
Maximum water tank pressure	870
Maximum water inlet pressure (to engine)	660
Minimum water inlet pressure (to engine)	500
Maximum water exit pressure	600
Minimum water exit pressure	135

6.1.2 LOX System Tests

Initially, the LOX system was evaluated with liquid nitrogen (LN_2). However, some of the engine thermocouple readings were suspicious, making it hard to evaluate the exact quality of LOX that would result in the system based on the temperature results. To properly verify the LOX system performance, remaining LOX blowdowns and cold flows were performed with LOX. (Eventually the thermocouples were calibrated to provide accurate and repeatable temperature measurements.)

Early tests experienced some leaks in the LOX system that were eliminated with minor hardware changes (including replacing the LOX prechill valve). Yet, for the most part, the LOX system provided consistent and appropriate operation for the cold flows conducted prior to the ignition tests. The cold flows showed the venturies cavitated properly and provided the desired flow rates. In addition, good quality LOX was available consistently for each test. (Only one test (GR'32) provided poor quality LOX when a full tank was unavailable. In this test, the GHe pressurant mixed with the residual LOX in the tank to create warm fluid temperatures.)

The final LOX system operation settings included regulating the LOX tank between 365 and 375 psia. This pressure range provided appropriate LOX venturi inlet pressures, ≈350 psia, for the required LOX flow rate to the engine. To detect anomalous behavior in the LOX system and initiate cutoff during the main flow, a redline value of 430 psia was set for the 20-percent (LOX) venturi inlet pressure. (Prior to main flow, this value was set higher (900 psia) to avoid any pressure spikes due to two-phase flow during initialization. Such spikes had been observed in early tests, particularly when LN_2 was used in the system.)

Appendix H provides additional data and details of the LOX system test results.

6.1.3 Fuel System Tests

All fuel cold flows and blowdowns were performed with GHe to minimize risks to the LASRE system. GHe provided an appropriate medium for these system checkouts, since the data were easily scaled to ensure required conditions would result when GH_2 was used. The fuel supply valve was regulated to provide a specific pressure at the venturi inlets, depending on the required flow rate.

In an early cold flow (GRUN0016), the poppet in the fuel valve actually broke off due to high cycle fatigue. With no containment feature downstream of the valve, the poppet flowed into the engine assembly where it became lodged in the manifolding. (The engine was removed from the model and physically rotated to retrieve the poppet. No internal damage to the engine system was observed.) The valve was redesigned to prevent such a failure from occurring again. Additional tests experienced leaks and irregular behavior from this valve. After the valve design was further reworked, the regulating system worked consistently with GHe to provide the required pressure for subsequent cold flows.

Nominal conditions provided ≈470 psia at each fuel venturi for the required flow rate. Redlines were used at the 20-percent (fuel) venturi inlet to detect any anomalies for cutoff. The maximum venturi pressure was limited to 700 psia during main flow, with a minimum value limited to 420 psia.

Appendix I provides additional data and details of the fuel system test results.

6.1.4 Ignition Tests

While preceding cold flows ensured the nominal and consistent operation of the water, LOX, and fuel system, four ignition tests were performed to check out the TEA-TEB system and optimize the ignition sequence. LOX was used to provide ignition with the resulting TEA-TEB flow, and GHe was still used in the fuel system. Water was provided in each test to appropriately cool the engine.

The performance of the TEA-TEB system was verified for both single (GR'31 and GR'32) and double burns (GR'33), since two canisters of TEA-TEB were available to operate independently. Both cartridges were successfully used, and the TEA-TEB ports in each thruster remained unclogged after each test. This was important, since small TEA-TEB ports can easily clog if not purged properly. While other component hardware allows easy access to remove such ports and clean them between tests, the contained design of the LASRE engine would not allow such access. Fortunately, the successful purges relieved this concern.

In addition, consistent and immediate ignition was achieved in all eight thrusters during each test. The ignition sequence timing was verified and results allowed the ignition detect value to be set. Each thruster provided a chamber pressure of ≈30 psig during ignition, so 15 psig was used for the minimum pressure required to ensure ignition. This pressure was sufficiently above the average chamber pressure (≈5 psig) provided prior to ignition, when only LOX and corresponding purges were present.

The resulting TEA-TEB flow from each cartridge provided ≈0.04 lb_m/sec to each thruster for less than 0.5 sec. The test sequence was reviewed to make sure fuel flow was initiated before all TEA-TEB was consumed (otherwise, the ignition source required for mainstage combustion would be eliminated). Although tests were run with both cartridges to verify the design of the system, only one cartridge was really necessary, since changes to the test plans eventually eliminated the required double burns.

Fuel manifold pressures began to increase slightly after the ignition tests were performed. These higher pressures were likely due to TEA-TEB residue in the fuel annuli and/or the BLC holes of the injectors. Such residue was not unexpected or unusual, especially without a positive purge on the fuel side of the injector during the ignition phase. However, even with this residue, analysis showed there was still plenty of fuel side flow area available in each injector. So, the results posed no threat to the hardware condition or the performance of each thruster. The pressures were monitored in subsequent tests to verify that adequate fuel side flow areas always remained available.

Appendix J provides additional data and details of the ignition test results.

6.1.5 Hot-Fire Tests

After all systems were verified to ensure nominal and consistent operation, a hot-fire test was attempted. The initial attempt caused the main fuel valve to fail when exposed to hydrogen for the first time during pretest servicing. The failure resulted when the bellows in the valve cracked due to hydrogen embrittlement. No hot-fire test was attempted, and the valve was removed for servicing. It was redesigned to use a compatible piston assembly instead of a bellows. After the redesigned valve was installed, two successful hot-fires were performed. Figure 7 shows one of these ground hot-fire tests.

Figure 7. Ground configuration hot-fire test.

The hot-fires provided the first opportunity to verify the performance of the fuel system with hydrogen. Data were successfully scaled based on the GHe performance, so proper pressures and flow rates resulted with GH_2. In addition, the entire test sequence was finally verified—fuel was properly provided to the engine prior to depleting the ignition source, allowing successful transition to mainstage, and all redline values appeared to be set appropriately.

Both tests were operated at mainstage chamber pressures of ≈220 psia in each thruster for 3 sec. Each provided confidence in the consistent operation of the entire system prior to performing hot-fires in flight. Inspections revealed that some thermal coating had spalled off each thruster's liner. However, this was not unexpected since the type of coatings applied have a history of such problems. Yet, no excessive hot spots were observed to indicate overheating, so each thruster remained in good condition after each hot-fire.

The data were used to calculate the performance of each thruster, and results were compared to those achieved for the single thruster at SSFL. The characteristic velocity, C^*, was used for the performance parameter on this component hardware. Its value was determined for the test conditions in each thruster and compared to the theoretical values to provide C^* efficiency results. The thrusters were not designed to provide high performance. So, absolute values were not as important as consistency between each thruster from test to test. (A degradation in performance between hot-fires can often indicate degradations within the hardware.)

Figure 8 compares the results for both hot-fires with those from SSFL. Since the single thruster testing was conducted over a range of conditions, the performance results provided C^* efficiencies from 83 to 95 percent. For each thruster in the LASRE engine, resulting C^* efficiencies ranged from 91 to 98 percent. Actually, when tested at similar conditions (P_c ≈200 psia, mixture ratio ≈6), the single thruster produced a C^* efficiency of ≈85 percent. Each thruster in the LASRE engine provided higher than expected performance results that remained consistent between hot-fires.

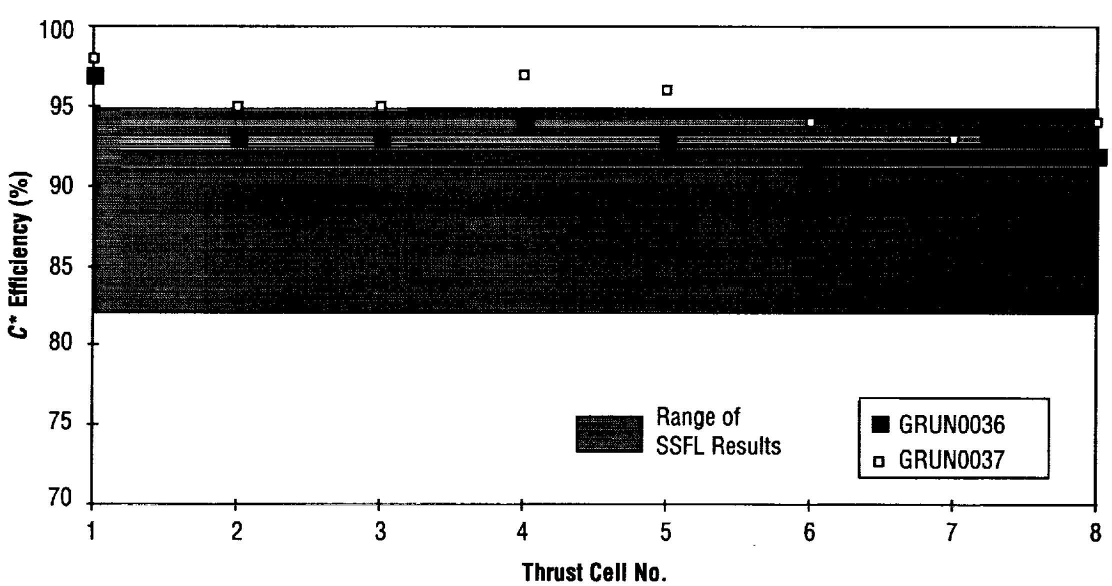


Figure 8. Thruster performance results in each hot-fire test.

Table 3 further compares the resulting hot-fire conditions with expected values. Required flow rates for the LASRE engine were determined by assuming a C^* efficiency of 85 percent, as observed for the single thruster in the SSFL testing. Since the performance of each LASRE engine thruster was actually higher than expected (probably fewer losses compared to the single thruster), the resulting chamber pressures for the two hot-fire tests were slightly higher than expected.

Table 3. Hot-fire results versus expected conditions.

Condition	Average P_c (psia)	Average Mixture Ratio	Average C^* Efficiency
Expected	~200	~6.0	~85%**
GRUN0036 results	220	5.6	93%
GRUN0037 results	220	5.6	95%

**Based on SSFL testing at P_C ~200 psia

Finally, the thermal performance of the engine was checked. Figure 8 shows the ramp temperatures responded appropriately with the rising chamber pressure, and final values remained well below the redlines set for cutoff. Furthermore, the responses remained consistent between tests, with the temperature rise only slightly higher in the second hot-fire.

Note in figure 9 that chamber pressures continued to rise slightly during mainstage instead of reaching a constant level. This occurred because of the increasing fuel flow rate supplied by the GH_2 system. A constant pressure was not maintained on the fuel tank, so after the main fuel valve opened, the tank pressure decreased as fuel flowed to the engine. As the tank pressure decreased, the temperature of the fuel decreased. Although the venturi inlet pressures were maintained at constant levels by regulating the fuel valve position, the decreasing temperatures increased the density of the fuel. Results created a corresponding increase in the fuel flow rate, which produced the rising chamber pressure levels.

Appendix K provides additional details on the hot-fire data results and supporting analyses.

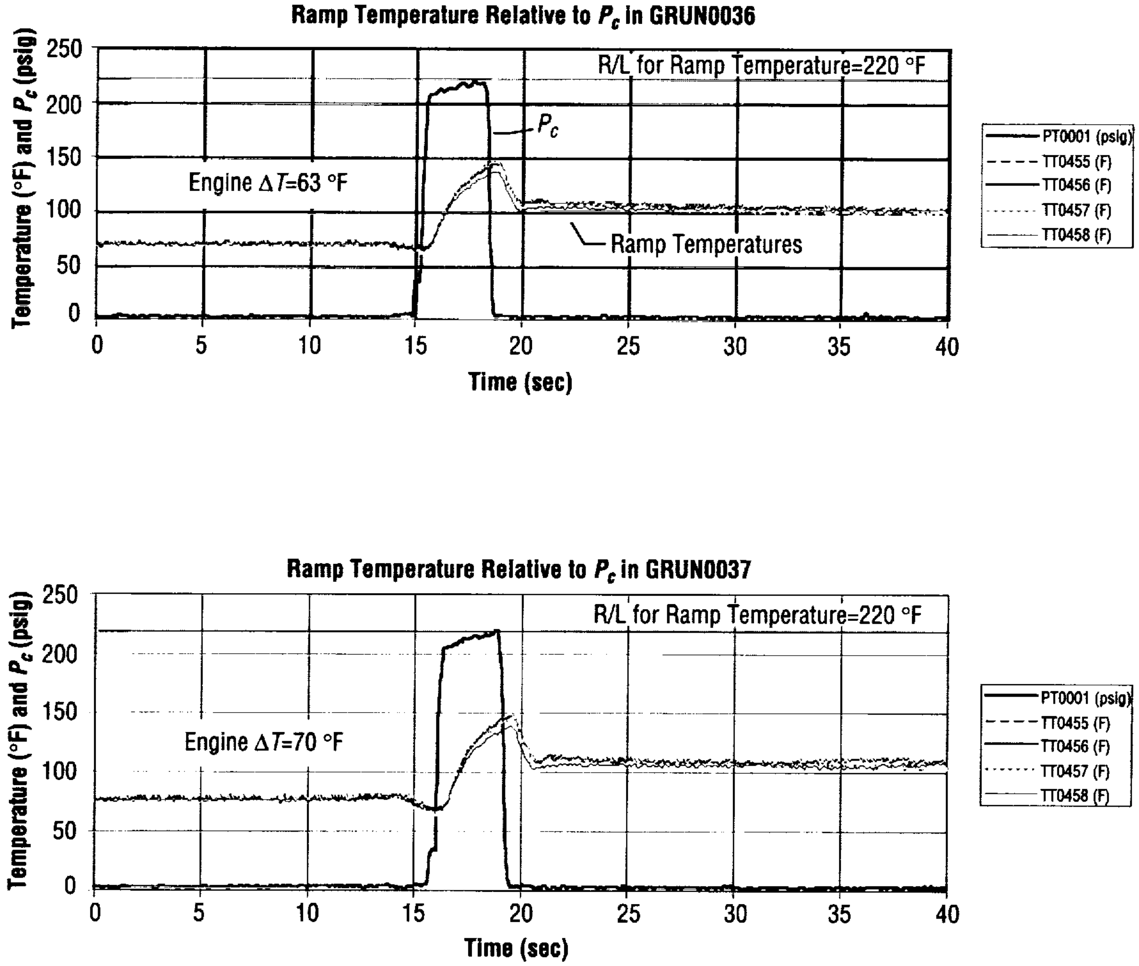


Figure 9. Ramp temperature responses in each hot-fire test.

6.2 Flight Configuration Testing

When ground testing was completed at Phillips Laboratory, the LASRE system was moved to DFRC's facilities to prepare the system for its flight configuration. To prepare the assembly for flight, all panels around the pod were installed to properly seal the assembly. After the assembly was attached to the SR–71, additional cold flows were performed to verify no changes had occurred that affected the performance established for each system. Several cold flows were conducted with the aircraft on the ground before proceeding with additional cold flows in flight. Figure 10 shows the pod being mounted to the aircraft for flight configuration testing.

While appendix F includes the steady-state data, appendix L provides transient data plots that compare flight configuration results with ground configuration tests.

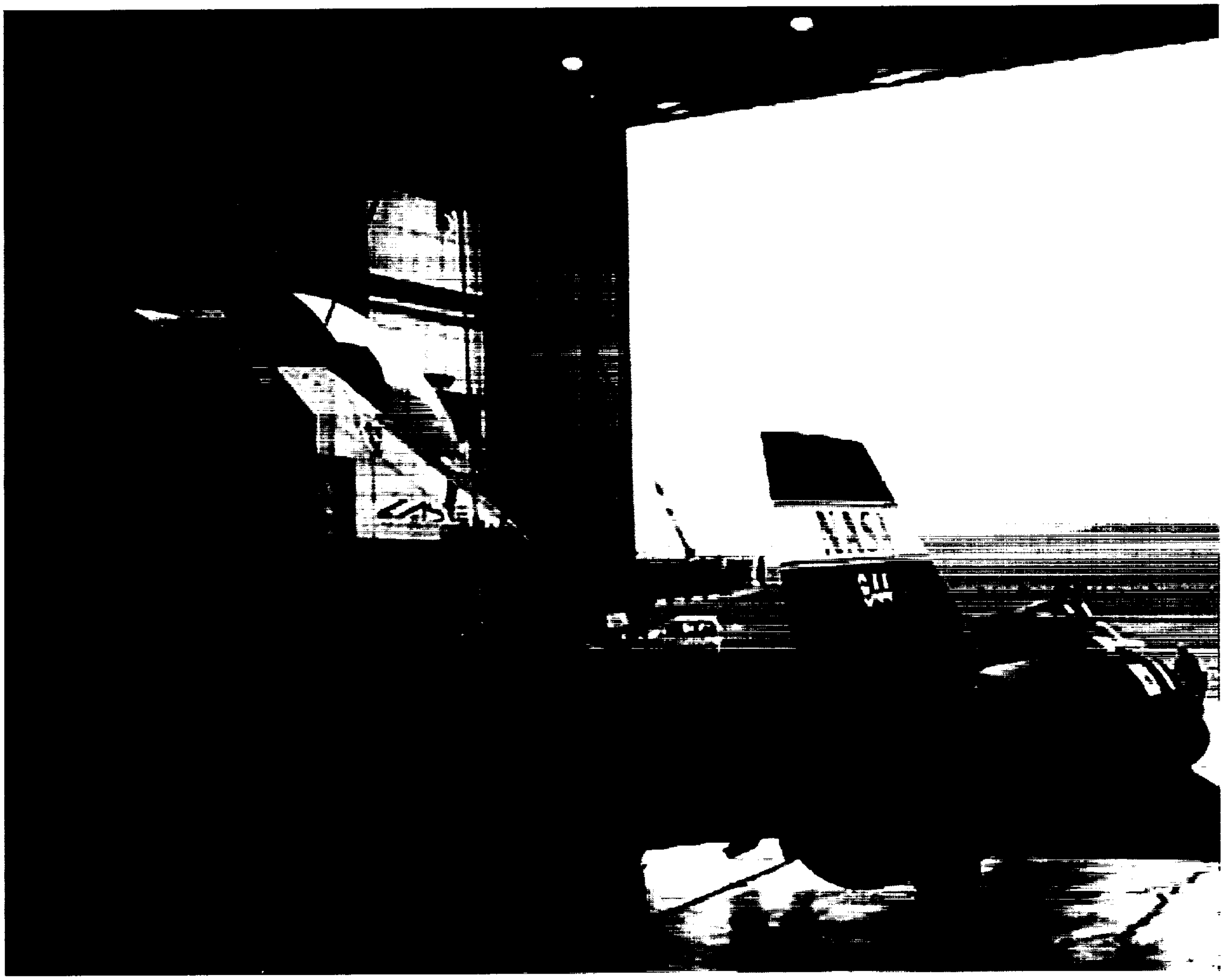


Figure 10. LASRE pod being mounted to SR–71.

6.2.1 Initial Ground Testing

Before tests in flight were attempted, four ground-level cold flows were conducted with the system in flight configuration. These were performed with LN_2 through the LOX system to alleviate concerns of LOX spilling on to the surface of the stationary aircraft. GHe was used in the fuel and TEA-TEB systems.

The LOX system continued to perform nominally with results consistent with those obtained during ground tests at Phillips Laboratory. Similarly, the fuel, TEA-TEB, water, and engine systems all continued to perform consistently when compared with results achieved at Phillips Laboratory.

Some difficulty was experienced with the system used to pressurize the LOX tank, but when properly pressurized, the supply system to the engine provided the pressures and flow rates required for the hot-fire conditions. It was suspected that the pressurizing problems were caused by a valve in the LOX vent line. Isolation tests suggested the valve was inadvertently opening and/or leaking and allowing pressure to escape the LOX system. Consequently, the tank could not achieve constant pressure, as desired. Further investigations attributed the problem to changes made in the pressurization sequence. While the original operating sequence used two valves to pressurize the LOX tank, a modification during flight configuration testing employed only one valve for this operation. The change apparently affected the LOX system dynamics enough to influence the behavior of the LOX vent valve. When the operating sequence was eventually modified to use both pressurizing valves again, the system problems were alleviated.

In addition, in GR'41, the "Emergency Shutoff Switch" was used to verify that implementing this procedure in the event of anomaly would provide a "safe" shutdown of the systems and hardware. An additional inadvertent shutdown would occur if power was lost to the system "controller." A shut-down to demonstrate this event was performed in GR'46, and results verified that the main LOX and fuel valves closed properly and isolated the engine, as designed.

6.2.2 Initial Flight Testing

Initial ground testing of the flight configuration established further confidence in all system operations. Cold flows were then conducted in flight to verify that nominal operation continued when systems were operated at speed and altitude. The resulting cold flow data compared very well with the ground cold flow data, and no major sequence changes for the engine were required.

The first two flight cold flows, FLT'47 and '48, used LN_2 in the LOX system (with GHe in the fuel and TEA-TEB systems). The cold flow in FLT'47 was conducted at 41,000 ft and a Mach number of 1.2; FLT'48 was conducted at 31,000 ft and a Mach number of 0.9. For these flights, all engine and supply systems performed nominally—results were consistent with ground test data. Figure 11 shows the water coolant being exhausted at the end of one of the initial flight tests.

Unfortunately, the LASRE pod structural assembly did not appear leak tight, as desired. A nitrogen purge of the pod was used. This purge was designed to keep air out of the contained assembly and minimize the presence of oxygen in the event of a fuel leak. Yet, the pod filled with air shortly after takeoff according to oxygen sensors positioned in the canoe assembly. Between tests, attempts were made to seal the assembly better. Results in the second test, FLT'48, showed some improvement, but more sealing was required to provide acceptable levels before a hot-fire could be attempted.

Figure 11. Water exhausted during first flight configuration test.

The third flight, FLT'49, was planned to conduct a cold flow along with an ignition test; so, LOX was provided along with a single load of TEA-TEB. GHe was used in the fuel system. The test was attempted at an altitude of 26,000 ft and a Mach number of 0.75. Unfortunately, no ignition was obtained because the TEA-TEB had been loaded in the wrong canister. (After this incident, the second canister was appropriately sealed, so this mistake could not happen again.)

However, the sequence still allowed a successful cold flow to be performed, so results were established using LOX in flight. All engine and system parameters performed nominally with results comparable to the first two flight cold flows.

The level of air leaks in the canoe were significantly reduced in FLT'49, so this structure appeared to be sealed much better. Unfortunately, oxygen sensors in the model indicated LOX leaks at unacceptable levels. Although these sensors were available in the model assembly during the other flights, LN_2 had been used in the system. The leaks were not detected until LOX was provided in this flight.

Except for the excessive leaks reported in the pod during the flight cold flows, the engine and propellant systems were operating nominally and consistently. In fact, the flight readiness review (FRR) was conducted at DFRC on May 7, 1998, to review the LASRE program and request that a hot-fire in flight be considered. However, the presence of the leaks created too much uncertainty, and additional tests were planned to address these leaks before a hot-fire in flight would be attempted.

6.2.3 Additional Tests for Leakage

Unfortunately, the design of the system allowed limited access to the internal structures, making it difficult to perform thorough leak checks. Evaluations of the propellant lines and the engine had to rely on the few sensors available within the pod for relative data and limited visual checks for actually locating possible leak paths.

To further investigate the integrity of the fuel system and check for hydrogen leaks, a ground test (GR'52) was conducted with a mixture of ≈3-percent GH_2 and 97-percent GHe through the fuel system. Hydrogen detectors were placed in various locations throughout the model to check for the presence of hydrogen when the fuel system was operated. The test was performed without the nitrogen purge, so hydrogen could be detected in an "unpurged" environment. The fuel system appeared leak tight, since no hydrogen was detected throughout the test.

Following FLT'49 when LOX leaks were first detected, a ground test (GR'47) was performed on the LOX system using LN_2. A visual check revealed a leak in the LOX prechill line. After repairs were made, the subsequent test (GR'48) showed no visible leaks with LN_2. However, GR'49 revealed a leak in the LOX purge line's check valve. The fittings on this valve were welded to eliminate the leak paths, and the next ground test (GR'50) indicated no visible leaks again.

These ground tests were relying on visual checks of the LOX system using LN_2. To verify the same results in flight with LOX using the available oxygen sensors, another cold flow was attempted in FLT'50. Once again, the sensors indicated leaks were present somewhere in the LOX system. Yet, the oxygen sensors in flight could not indicate the exact location of the leaks, so further ground tests were performed to locate the leaks with visual checks on the system.

Visual checks were performed in GR'53–56 with LN_2. Minor leaks were found and fixed in various parts of the system. When leaks could no longer be visually detected, GR'57–59 were performed with LOX in the system so the oxygen sensors could be used. (Although initial concerns prevented previous ground testing with LOX on the stationary aircraft, its surface was covered appropriately so this testing could be performed.) Visual checks could not be performed at the same time because in order to use the oxygen sensors the assembly had to be completely sealed.

Leaks were again detected with the sensors, so further visual checks with LN_2 were performed in GR'60. In this test, all accessible joints and fittings were bagged using clear plastic material. Results indicated some leakage downstream of the main LOX valve. The seal in its fitting was replaced and when GR'61 was performed with LN_2, no visual leaks were observed. GR'62 attempted to use LOX and handheld oxygen sensors, but these sensors were inoperable, providing no useful leak detection.

Finally, GR'63 used LOX again and relied on the oxygen sensors available in the pod. Results showed leak rates as high as 4.5 percent after the LOX autosafe procedure was performed. To determine the altitude effects on these apparent leakage measurements, another LOX system blowdown in flight was attempted in FLT'51. The tests were performed at an altitude of 31,000 ft and a Mach number of 0.9. Results actually indicated higher leak rates than those observed on the preceding ground test; values reached 9.5 percent after the LOX autosafe procedure.

This final flight test (FLT'51) was conducted on October 29, 1998. At this point it appeared that without a significant cost and schedule impact, the supply systems would never be leak tight to the levels required by the FRR board for safely performing a hot-fire in flight. On November 20, 1998, NASA announced the conclusion of the LASRE program.

7. CONCLUSION

The LASRE program proved to be a very challenging project for NASA, the associated contractors, and the Air Force. Yet, along with numerous cold-flow tests, two successful hot-fire tests were conducted on the LASRE system at Phillips Laboratory. Each of these tests provided data at chamber pressures of ≈220 psia and mixture ratios close to 6 in the aerospike engine for 3 sec. After ground configuration testing, the system was successfully integrated with the SR–71 aircraft for the flight test program at DFRC.

Although successful hot-fire tests were never conducted in flight, a lot of useful data were obtained for the aerospike engine design. In addition to the ground level hot-fire data, the cold-flow data obtained in flight at various altitudes and speeds may prove useful for further evaluating this engine configuration.

Also, the overall integration of the LASRE system with the SR–71 proved successful. Although leaks in the engine supply systems could not be sufficiently eliminated, the aircraft performed well to achieve specific data in flight. As a result, this program further demonstrated that such aircraft could be successfully used as a valuable tool for evaluating other vehicle and engine concepts in a similar manner.

APPENDIX A—Single Thruster Testing and Failure Investigation

A.1 Single Thruster Testing

Rocketdyne fabricated nine thruster assemblies, including eight for the LASRE engine. The additional thruster was tested at SSFL to verify the design and recommended operating sequence. Objectives included operating the single thruster over the chamber pressure range expected for the LASRE engine (200–300 psia) with various mixture ratio levels (4.5–7). In addition, this thruster was supposed to be tested for 1.5 times the total duration expected on the LASRE engine. Original test plans for the LASRE engine included 40 tests for 3 sec each—for a total duration of 120 sec. The SSFL program planned durations of 3, 12, and 40 sec to accumulate a total of 180 sec on the single thruster.

Twelve mainstage tests were actually conducted in September and October of 1995. Chamber pressures ranged from 188–307 psia with various mixture ratio levels. Each test lasted 3, 12, or 40 sec in duration. A total of 112 sec was accumulated on the single thruster before a failure in the 12th test ended the program.

The failure damaged the liner's upper surface, just downstream of the throat, as shown in figure 12. The surface in the damaged area was roughened and burned for several inches. The liner burned through to the coolant side in one localized area around coolant hole No. 10. (Prior to the failure, the thermal barrier coating had begun to spall off in the chamber. However, this was not unusual or unexpected, since the type of coatings used have a history of spalling in similar test environments.)

Inspections revealed the buildup of calcium carbonate ($CaCO_3$) deposits in nearly every coolant channel. The heaviest concentration was in the channels around the damaged area. Since deionized water was not available for this program at SSFL, the calcium in the facility water system reacted with the high coolant temperatures during the hot-fires and created the solid scale buildup along the coolant channel surfaces.

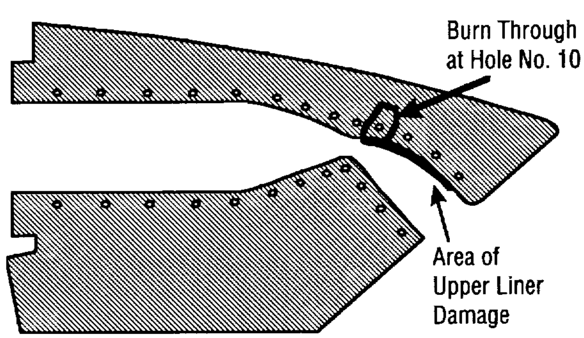


Figure 12. Damage to liner after failure.

The deposits decreased the effectiveness of the cooling water by creating a layer of low conductivity material along the coolant side of the liner. The coolant could not effectively transfer the heat that built up on the liner's hot wall. The resulting temperature rise on the hot wall was eventually high enough to melt the copper surface and burn through. (A similar problem was experienced by MSFC (circa 1987) when scale deposits from facility water eventually caused a calorimeter chamber to burn up. After this incident, MSFC always used deionized water in its test programs. Rocketdyne normally uses deionized water also, but it was not available for this program at SSFL.) A similar failure was not expected for the LASRE engine, since all components were cooled with deionized water.

The failure of the single thruster raised additional concerns and prompted additional analyses of the thruster design. During the failure investigation, detailed reviews of the hardware design, operating levels, and the original analyses were conducted. The original thermal analysis predicted the "hottest" region would be located directly upstream of the throat. However, the location of the failure suggested the "hottest" region was directly downstream of the throat, since the amount of $CaCO_3$ formation was proportional to the water temperature. In addition, the original analysis assumed equal coolant distribution among the 25 coolant holes, with 4 percent of the coolant flow provided to each.

However, Rocketdyne was able to make an aluminum replica of the thruster assembly, and when they performed water flow tests on this replica they found that the coolant distribution varied significantly, as illustrated in figure 13. The coolant holes near the injector end received the largest distribution of coolant, while those near the throat received the least amount of coolant flow. Therefore, the coolant flow was not optimized, since the injector end experienced much lower heating rates compared to the throat area. In other words, the area that needed the most coolant was, in fact, receiving the least amount. So, the original analysis was inaccurate since it assumed at least 4 percent of the coolant flow would be available to cool the throat area, when actually only 2.8–3.2 percent of the flow was provided.

As a result, new CFD and thermal analyses were performed by MSFC and reviewed with Rocketdyne. Results showed the maximum heat flux was higher than originally predicted. When accounting for this higher heat flux and the nonuniform coolant distribution, the maximum wall temperatures were higher than originally predicted. In addition, the new thermal analysis showed the potential for film boiling, which would create a vapor phase of water in the coolant, reducing the effectiveness of the liquid coolant. The presence of film boiling would create even higher wall temperatures.

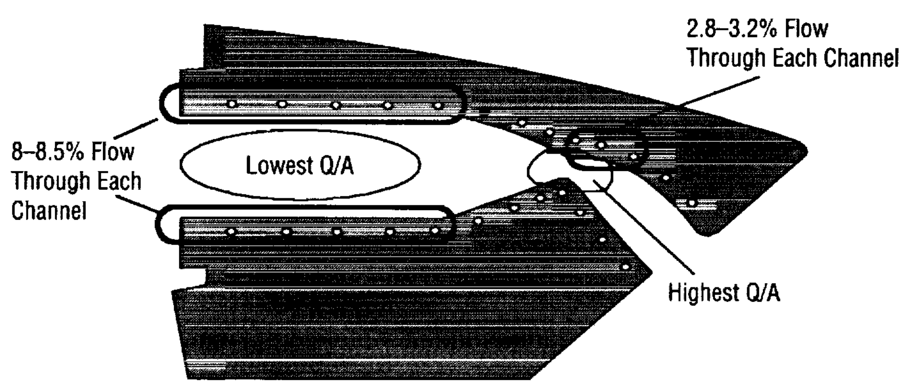


Figure 13. Actual coolant distribution through coolant channels.

When these results were shared with Rocketdyne, additional analyses were performed that concluded no thermal safety margins were available for operating the LASRE engine thrusters at chamber pressures as high as 300 psia. Minimal but acceptable margin was available for operating at chamber pressures of 200 psia. For conservative operation, it was therefore recommended that system changes be attempted to increase the amount of coolant flow available, or limit the LASRE engine testing to chamber pressures of 200 psia.

("Minimal margin" indicated less margin (≈10 percent) than normally provided for flight hardware (60 percent). The LASRE engine was considered "workhorse" hardware with a limited number of short duration tests planned. So, while the minimal margin available was not optimal, it was acceptable for the LASRE test program. In addition, any detrimental effects from "overheating" would be gradual and evident from visual inspections of the hardware, so no catastrophic failure was implied from the reduced margin available during operation.)

The results of the single thruster failure and subsequent analyses did create some changes to the test conditions planned for the LASRE engine. Original hot-fire test conditions included chamber pressures of 200, 250, and 300 psia with vectored burns performed by operating one side of the engine at 200 psia and the other side at 300 psia. With the thermal margin concerns, all testing was limited to a conservative chamber pressure of 200 psia after the water blowdowns of the LASRE system showed that higher coolant flow rates were unavailable. However, the chamber pressure of 200 psia was considered adequate for obtaining data necessary to evaluate the aerospike engine performance. (These plans did not preclude testing at higher chamber pressures or vectored conditions later in the program. If enough confidence in the hardware existed after flight hot-fire test results and hardware inspections, higher chamber pressures and/or a vectored burn would have been considered for the final flight hot-fire test.)

APPENDIX B—Design Limits of LASRE Engine Components

As required, engine components (table 4) were proof tested to 1.5 × maximum expected operating pressure (MEOP). Also, a factor of safety (F.S.) on ultimate >2.25 was required.

All welds were class 1 inspected (x-rayed to verify penetration), ultrasonic inspections of critical braze joints were performed, and all joints proof tested/leak checked.

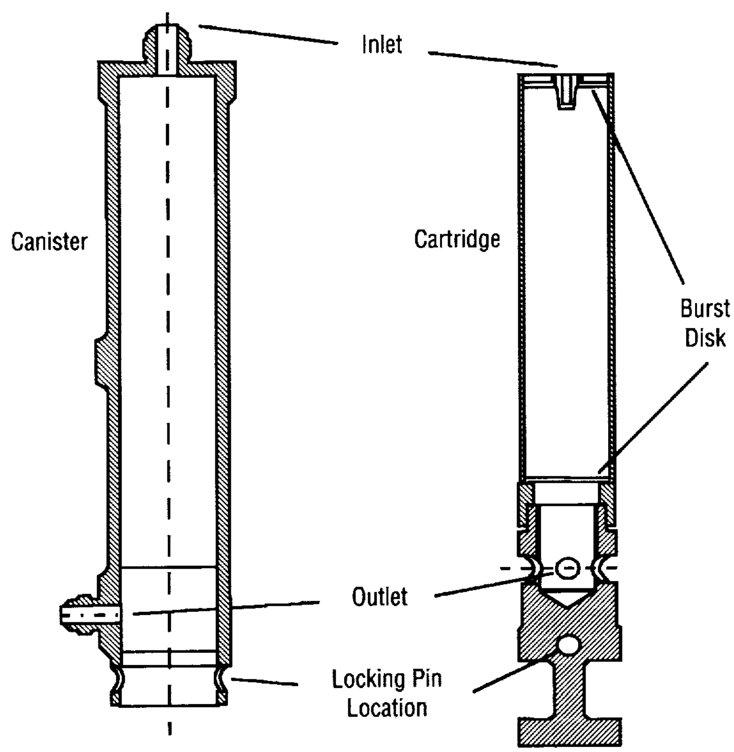
Table 4. Engine component testing specifications.

Component	Max. Operating P (psi)	Max. Operating T (°F)	Proof Pressure at 70 °F (psi)	F.S. at Operating Conditions Ultimate	F.S. at Operating Conditions Yield
Injector assembly alone					
GH_2	445	70	668	6.0	2.2
LOX	502	–290	668	20.0	4.8
Combustor assembly alone					
H_2O	600	170	987*	20.0	13.0
Thruster assembly hot gas joint	300	500	525	4.6	1.4
System plumbing (not attached to engine)					
GH_2	460	70	690	6.0	2.2
LOX	526	–290	575*	20.0	4.8
H_2O	600	170	1,038*	5.3	2.0
Nozzle assembly (w/H_2O inlets, mfds, ramps, fences)					
H_2O	450	–	–	>4.0	>1.5
RD plumbing to engine banks (including venturies, valves, tees, etc.)					
GH_2	600	70	–	>4.0	>1.5
LOX	600	–290	–	>4.0	>1.5
H_2O	600	170	–	>4.0	>1.5

*Includes environmental correction factor: ECF=(Ftu at T_{proof}/Ftu at T_{oper})
(proof P = 1.5xMEOPxECF)

APPENDIX C—LASRE System Design Details

Details of the LASRE system design are shown in figures 14 and 15 and the line list, system parts list, and interface list are shown in tables 5–7, respectively.



- Hypergolic with LOX
- Supplied with flight-proven Atlas MA–5A cartridges
  - Two cartridges on each flight
  - 68 g of TEA-TEB in each cartridge
  - Dual-burst disk configuration (DOT certified)
  - Canisters for cartridges delivered by Rocketdyne with engine

Figure 14. TEA-TEB ignition system.

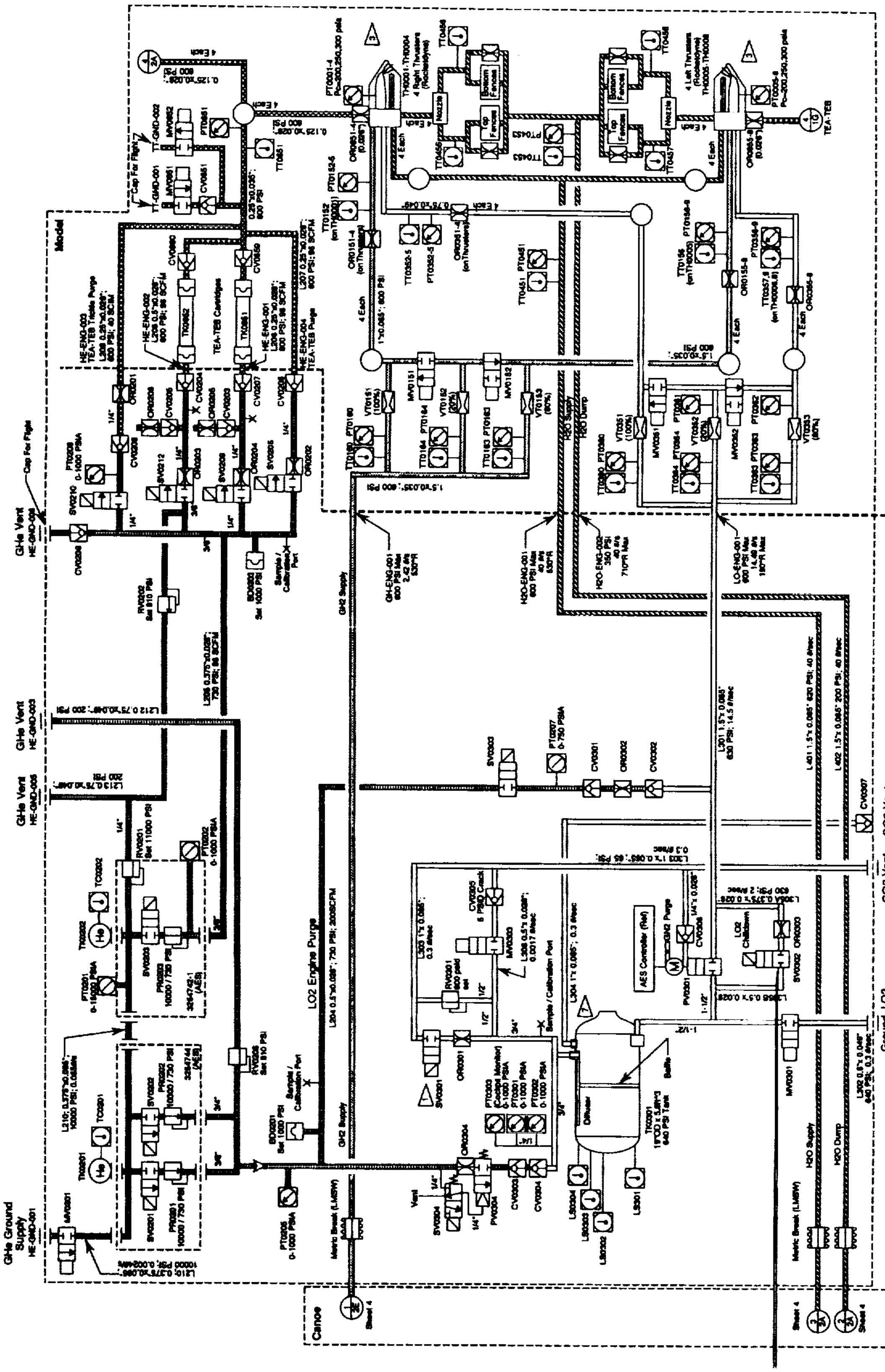


Figure 15. Detailed schematic of LASRE systems, reference Rev. H of drawing ALS–LASRE–10000.

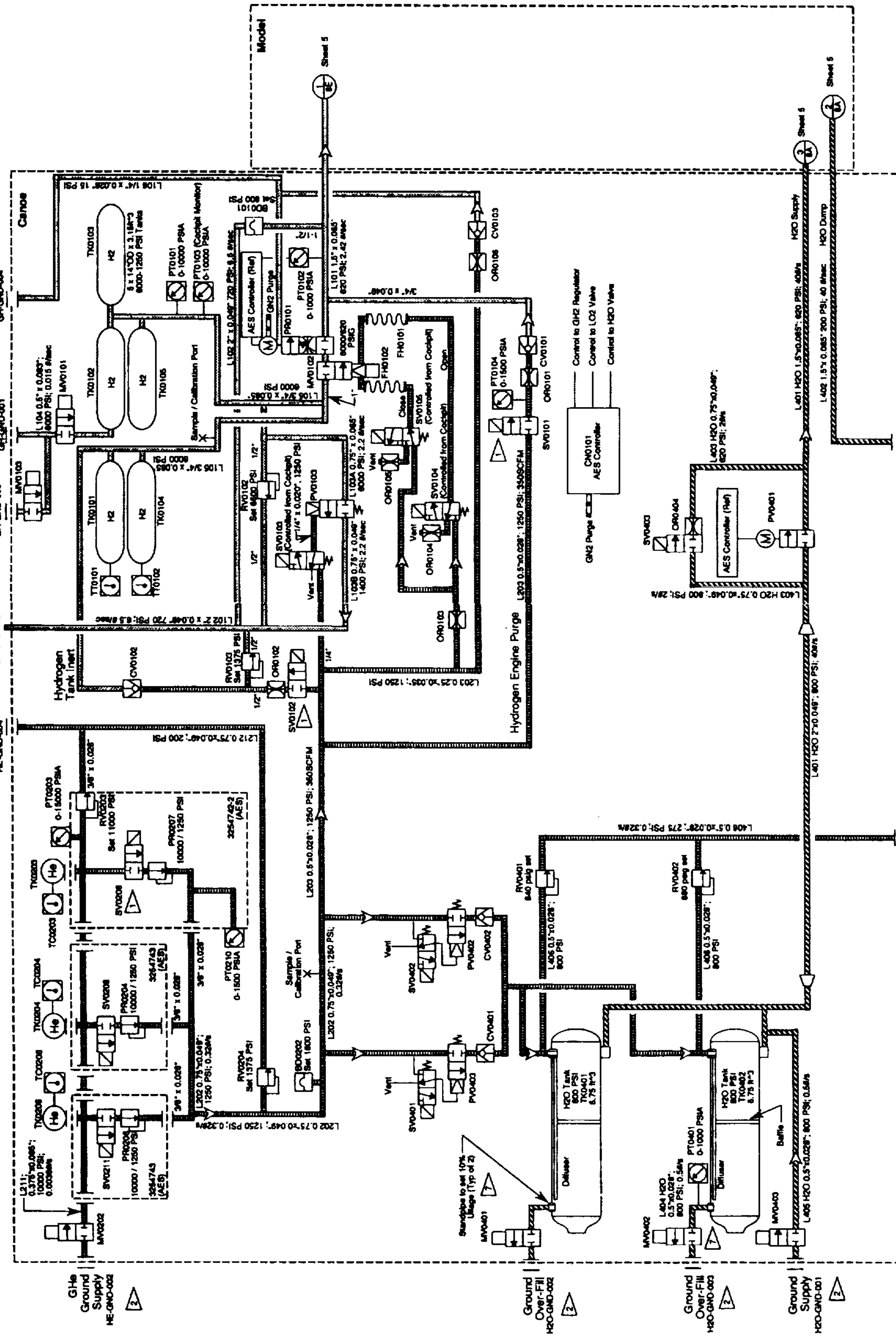


Figure 15. Detailed schematic of LASRE systems, reference Rev. H of drawing ALS–LASRE–10000 (Continued).

Table 5. LASRE line list.

LASRE Line List 5/27/97

	Ult Tensile Strength (psi)	Yield (psi)	
	75000	30000	321 CRES PER MIL-T-8808
	105000	75000	1/8 hard 304 CRES per AMS 5566 (Labelled w/*)

Factor of Safety	2.5	on ultimate
	1.5	on yield

Line Number	Line Name	Fluid	Pressure (psia)	Temp (°R)	Line Size (in)	Length (ft)	Flowrate (#/s)	Min Reqd Wall (in)	Selected Wall (in)	Notes
L101	GH2 Supply to Engine	GH2	600	400-530	1.500	11.2	2.42	0.023	0.065	
L102	GH2 Relief Valve Vent	GH2	720	530	2.000	6.0	6.50	0.036	0.049	
L103A	GH2 Cockpit Vent	GH2	6000	530	0.750	6.0	2.18	0.054*	0.065	Upstream of Vent Valve PV0103
L103B	GH2 Cockpit Vent	GH2	1150	530	0.750	6.0	2.18	0.022	0.049	Downstream of Vent Valve PV0103
L104	GH2 Fill/Vent	GH2	6000	530	0.500	4.0	0.015	0.075	0.083	
L105	GH2 Tanks to Regulator	GH2	6000	400-530	0.750	26.1	2.42	0.054*	0.065	
L106	H2 Regulator Seal Vent	GH2	15	530	0.250	10.0	1 SCIM	0.000	0.028	
L201	He Press of LO2 Tank	GHe	730	400-530	0.750	4.0	0.26	0.014	0.049	
L202	He Press of H2O Tank	GHe	1250	400-530	0.750	6.0	0.27	0.023	0.049	
L203	He Purge of GH2 System	GHe	1250	530	0.500	30.0	350 SCFM	0.016	0.028	
L204	He Purge of LO2 System	GHe	730	530	0.500	30.0	200 SCFM	0.009	0.028	
L205	TEA-TEB Helium Supply	GHe	730	530	0.375	5.0	96 SCFM	0.007	0.028	
L206	TEA-TEB Press/Purge	GHe	730	530	0.250	3.0	96 SCFM	0.005	0.028	
L207	TEA-TEB System Purge	GHe	730	530	0.250	3.0	96 SCFM	0.005	0.028	
L208	TEA-TEB Trickle Purge	GHe	730	530	0.250	3.0	40 SCIM	0.005	0.028	
L210	GHe Fill - Model	GHe	10000	530	0.375	4.0	0.0024	0.045*	0.065	
L211	GHe Fill - Canoe	GHe	10000	530	0.375	4.0	0.0036	0.045*	0.065	
L212	He Vent - Model Bottom	GHe	200	400-530	0.750	15.0	0.41	0.004	0.049	
L213	He Vent - Model Top	GHe	200	400-530	0.750	15.0	0.26	0.004	0.049	
L301	LO2 Supply to Engine	LO2	600	162-190	1.500	8.0	14.50	0.023	0.065	
L302	LO2 Fill/Drain	LO2	600	162-190	0.500	4.0	0.30	0.008	0.049	
L303	LO2 Tank Vent	GO2/GHe	600	162-190	1.000	6.0	0.30	0.015	0.065	65 PSI Downstream of Valve
L304	LO2 Tank Overflow	GO2/GHe	600	162-190	1.000	6.0	0.30	0.015	0.065	65 PSI Downstream of Valve
L305A	LO2 Engine Chilldown	LO2	600	162-190	0.375	3.0	2.00	0.006	0.028	
L305B	LO2 Engine Chilldown	LO2	600	162-190	0.500	3.0	2.00	0.008	0.028	
L306	LO2 Tank Regulated Vent	GO2/GHe	600	162-190	0.500	5.0	0.0017	0.008	0.028	65 PSI Downstream of Valve
L401A	H2O Supply to Engine	H2O	800	530	1.500	40.0	40.00	0.030	0.065	
L401B	H2O Supply to Engine	H2O	800	530	2.000	40.0	40.00	0.040	0.049	From tank manifold to shutoff valve
L402	H2O Return from Engine	H2O	200	710	1.500	40.0	40.00	0.008	0.065	
L403	Engine Cooldown	H2O	800	530	0.750	5.0	2.00	0.015	0.049	
L404	H2O Tank Overflow	H2O	800	530	0.500	5.0	0.50	0.010	0.028	
L405	H2O Fill/Drain	H2O	800	530	0.500	5.0	0.50	0.010	0.028	
L406	H2O Tank Relief	GHe/H2O	800	530	0.500	5.0	0.32	0.010	0.028	

ALS-LASRE-10000 Rev H

Table 6. LASRE propulsion system parts list.

Ref Des	Nomenclature	Fluid	Pressure (psia)	Temp (oR)	Line Size (in)	Flow rate (#/s)	Part No.	Supplier	Notes	Line No.
Vehicle Gaseous Hydrogen Subsystem										
BD0101	GH2 Engine Supply Burst Disk	GH2	800	530	1.5	6.5	Holder,1-1/2" Type BU; Disk, 1-1/2" Type SCRD-V CRES	Fike	800 PSID Burst. Part has a reverse pressure support feature.	L102
CN0101	Allied Signal Controller	N/A	N/A	N/A	N/A	N/A	3254709	Allied		
CV0101	Engine Purge Check Valve	GH2	820	530	0.5	350SCFM	220T-8JJ	Circle Seal		L203
CV0102	GH2 Tank Inert Check Valve	GH2	6000	530	0.5	100SCFM	H220T-8JJ	Circle Seal		L203
CV0103	PR0101 Seal Vent Check Valve	He	25	530	0.25	750 SCIM	MS24593-1	Crissair		L203
FH0101	MV0102 Pneumatic Control Flex Hose - Open	He	1250	530	0.25	N/A	MIL-H-27267	N/A	0.010" Drill	L203
FH0102	MV0102 Pneumatic Control Flex Hose - Close	He	1250	530	0.25	N/A	MIL-H-27267	N/A	0.010" Drill	L203
MV0101	GH2 Tank Fill Valve	GH2	6000	530	0.5	0.15	81875-8KR	Dragon		L104
MV0102	GH2 Ground Safety Shut-off Valve	GH2	6000	530	1	2.42	MS-VV16T	Hi-Gear	w/ 74A695230-1003 Actuator	L105
MV0103	GH2 Quick Disconnect Vent Valve	GH2	6000	530	0.5	N/A	SSNG250-4T	Robbins		L104
OR0101	Hydrogen Purge Orifice	He	1250	530	0.5	350SCFM	AA1634-8K	Allen Aircraft	0.16" Drill	L203
OR0102	GH2 Tank Inert Orifice	He	1250	530	0.5	100SCFM	AA1634-8K	Allen Aircraft	0.085" Drill	L203
OR0103	MV0102 Pneumatic Control Orifice	He	1250	530	0.25	N/A	Conical Seal Orifice	N/A	0.010" Drill	L203
OR0104	MV0102 Pneumatic Control Orifice - Open	He	1250	530	0.25	N/A	Conical Seal Orifice	N/A	0.010" Drill	L203
OR0105	MV0102 Pneumatic Control Orifice - Close	He	1250	530	0.25	N/A	Conical Seal Orifice	N/A	0.010" Drill	L203
OR0106	PR0101 Seal Vent Check Orifice	He	1250	530	0.25	750 SCIM	VDLM4326730H	Lee Co.		L203
PR0101	GH2 Regulator/Shut-off Valve	GH2	6000	530	1.5	2.42	3269636	Allied		L101
PT0101	GH2 Tank Pressure Transducer	GH2	6000	530	0.25	N/A	AP122DV-1e-2c-5b-9b	Sensotec	0-10000 PSIA Model TJE/A577-02-01	L104
PT0102	GH2 Engine Supply Pressure Transducer	GH2	620	530	0.25	N/A	A-5/8327-12	Allied/ Sensotec	0-1000 PSIA	L101
PT0103	GH2 Tank Pressure Transducer	GH2	6000	530	0.25	N/A	AP122DV-1e-2c-5b-9b	Sensotec	Monitored from Cockpit, 0-10000 PSIA, Model TJE/A577-02-01	L104
PT0104	GH2 Engine Purge Pressure Transducer	GHe	1250	530	0.25	N/A	PA324TC-1.5M	Statham	0-1500 PSIA	L203
PV0103	GH2 Tank Vent Valve	GH2	6000	530	0.75	2.18	KP14660	Keane	Cv=2.295, Note 9	L103
RV0102	GH2 Tank Relief Valve	GH2	6000	530	0.5	0.015	5349T-8BB-6600	Circle Seal		L102
RV0103	GH2 Tank Inert Relief Valve	GH2	1250	530	0.5	0.015	5120T-8TJ-900	Circle Seal	Reset as high as possible; Relieves in the event CV0102 leaks	L102
SV0101	Hydrogen Purge Shutoff Valve	He	1250	530	0.5	350SCFM	KS14709	Keane	A=0.006in^2	L203
SV0102	GH2 Tank Inert Shutoff Valve	He	1250	530	0.5	100SCFM	KS14709	Keane	A=0.006in^2	L203
SV0103	PV0103 Control Valve	He	1250	530	0.25	N/A	KS14655	Keane	Controlled from cockpit	L203
SV0104	MV0102 Control Valve - Open	He	1250	530	0.25	N/A	MV74	Marotta	Controlled from cockpit	L203
SV0105	MV0102 Control Valve - Close	He	1250	530	0.25	N/A	MV74	Marotta	Controlled from cockpit	L203
TK0101	GH2 Tank	GH2	6000	530	1	0.5	5001536	Structural Composites	Supplied by DFRC	L105
TK0102	GH2 Tank	GH2	6000	530	1	0.5	5001536	Struc Comp	Supplied by DFRC	L105
TK0103	GH2 Tank	GH2	6000	530	1	0.5	5001536	Struc Comp	Supplied by DFRC	L105
TK0104	GH2 Tank	GH2	6000	530	1	0.5	5001536	Struc Comp	Supplied by DFRC	L105
TK0105	GH2 Tank	GH2	6000	530	1	0.5	5001536	Struc Comp	Supplied by DFRC	L105
TT0101	GH2 Tank Temperature Transducer	GH2	6000	200-800	0.25	N/A	49-12()-80/+115C	Scientific Inst		N/A
TT0102	GH2 Tank Temperature Transducer	GH2	6000	200-800	0.25	N/A	49-12()-80/+115C	Scientific Inst		N/A

Table 6. LASRE propulsion system parts list (Continued).

LASRE Propulsion System Parts List

9/22/97

Ref Des	Nomenclature	Fluid	Pressure (psia)	Temp (oR)	Line Size (in)	Flow rate (#/s)	Part No.	Supplier	Notes	Line No.
Vehicle Helium Subsystem										
BD0201	GHe Supply Burst Disk - Model LO2	He	730	530	0.5	0.2	Holder,1/2" Type BU; Disk, 1/2" Scored Disk, CRES	Fike	1000 PSID Burst.	L201
BD0202	GHe Supply Burst Disk - Canoe	He	1250	530	0.5	0.3	Holder,1/2" Type BU; Disk, 1/2" Scored Disk, CRES	Fike	1600 PSID Burst.	L201
BD0203	GHe Supply Burst Disk - TEA-TEB	He	730	530	0.5	0.1	Holder,1/2" Type BU; Disk, 1/2" Scored Disk, CRES	Fike	1000 PSID Burst.	L201
CV0203	T-TEB Cannister #1 Bleed Check Valve	He	730	530	0.25	N/A	428-4ZT-24	Republic		L206
CV0204	T-TEB Cannister #2 Bleed Check Valve	He	730	530	0.5	96 SCFM	220T-8JJ	Circle Seal		L206
CV0205	T-TEB Cannister #2 Bleed Check Valve	He	730	530	0.25	N/A	488-4SST-5	Republic	0.016" Drill	L206
CV0206	T-TEB Trickle Purge Check Valve	He	730	530	0.25	40SCIM	220T-8JJ	Circle Seal		L208
CV0207	T-TEB Cannister #1 Press Check Valve	He	730	530	0.25	96 SCFM	220T-8JJ	Circle Seal		L206
CV0208	T-TEB Purge Check Valve	He	730	530	0.25	96 SCFM	220T-8JJ	Circle Seal		L207
CV0209	T-TEB Arming Vent Check Valve	He	730	530	0.25	N/A	220T-8JJ	Circle Seal		L206
MV0201	Model GHe Tank Fill Valve	He	10000	530	0.375	0.0024	20SC6071	Autoclave		L210
MV0202	Canoe GHe Tank Fill Valve	He	10000	530	0.375	0.0026	20SC6071	Autoclave		L211
OR0201	T-TEB Trickle Purge Orifice	He	730	530	0.25	40SCIM	VDLA4316135T	Lee Co.		L208
OR0202	T-TEB Purge Orifice	He	730	530	0.25	96 SCFM	AA1634-4K	Allen Aircraft	0.11" Drill	L207
OR0203	T-TEB Cannister 1 Pressurization Orifice	He	730	530	0.25	96 SCFM	Conical Seal Orifice	N/A	0.11" Drill, CRES	L207
OR0204	T-TEB Cannister 2 Pressurization Orifice	He	730	530	0.25	96 SCFM	AA1634-4K	Allen Aircraft	0.11" Drill	L207
OR0205	T-TEB Cannister #1 Bleed Orifice	He	730	530	0.25	N/A	Conical Seal Orifice	N/A	0.16" Drill, CRES	L206
OR0206	T-TEB Cannister #2 Bleed Orifice	He	730	530	0.25	N/A	Conical Seal Orifice	N/A	0.16" Drill, CRES	L206
PR0201	Helium Tank Pressure Regulator - Model	He	10000	530	0.375	0.09	KCR14627	Keane	Part of Manifold 3254744;A=0.0067in^2	L201
PR0202	Helium Tank Pressure Regulator - Model	He	10000	530	0.375	0.09	KCR14627	Keane	Part of Manifold 3254744;A=0.0067in^2	L201
PR0203	Helium Tank Pressure Regulator - Model	He	10000	530	0.375	0.09	KCR14627	Keane	Part of Manifold 3254742-1;A=0.0067in^2	L201
PR0204	Helium Tank Pressure Regulator - Canoe	He	10000	530	0.375	0.09	KCR14521	Keane	Part of Manifold 3254743;A=0.0067in^2	L202
PR0206	Helium Tank Pressure Regulator - Canoe	He	10000	530	0.375	0.09	KCR14521	Keane	Part of Manifold 3254743;A=0.0067in^2	L202
PR0207	Helium Tank Pressure Regulator - Canoe	He	10000	530	0.375	0.09	KCR14521	Keane	Part of Manifold 3254742-2;A=0.0067in^2	L202
PT0201	Helium Tank Pressure Regulator - Model	He	10000	530	0.25	N/A	AP122EJ-1e-2c-5b-9b	Sensotec	0-15000 PSIA, Model TJE/A577-01-01	L210
PT0202	Helium Supply Pressure Transducer - Model	He	730	530	0.25	N/A	AP122CV-1e-2c-5b-9b	Sensotec	0-1000 PSIA, Model TJE/A578-01-01	L201
PT0203	Helium Tank Pressure Transducer - Canoe	He	10000	530	0.25	N/A	AP122EJ-1e-2c-5b-9b	Sensotec	0-15000 PSIA, Model TJE/A577-01-01	L211
PT0205	TEA-TEB He Supply Pressure Transducer	He	730	530	0.25	N/A	AP122CV-1e-2c-5b-9b	Sensotec	0-1000 PSIA, Model TJE/A578-01-01	L206
PT0207	LO2 Feedline Purge Pressure Transducer	He	730	530	0.25	N/A	AP122CT-1e-2c-5b-9b	Sensotec	0-750 PSIA, Model TJE/A578-02-01	L204
PT0208	TEA-TEB Trickle Purge Pressure Transducer	He	730	530	0.25	N/A	AP122CV-1e-2c-5b-9b	Sensotec	0-1000 PSIA, Model TJE/A578-01-01	L208
PT0210	Helium Supply Pressure Transducer - Canoe	He	1250	530	0.25	N/A	PA324TC-1.5M	Statham	0-1500 PSIA	L202
RV0201	Helium Tank Relief Valve - Model	He	10000	530	0.5	0.41	409M4F4Q	Pneu Hydro	Cv=0.09, Part of Manifold 3254742-1	L212
RV0202	TEA-TEB He Supply Relief Valve	He	700	530	0.5	0.41	51320-3110	Fluid Mech	Cv=1.5 (Fluid Mechanics)	L212
RV0203	Helium Tank Relief Valve - Canoe	He	10000	530	0.5	0.41	409M4F4Q	Pneu Hydro	Cv=0.09, Part of Manifold 3254742-2	L212

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Table 6. LASRE propulsion system parts list (Continued).

Ref Des	Nomenclature	Fluid	Pressure (psia)	Temp (oR)	Line Size (in)	Flow rate (#/s)	Part No.	Supplier	Notes	Line No.
Vehicle Helium Subsystem (cont.)										
RV0204	Helium Supply Relief Valve - Canoe	He	1250	530	0.5	0.41	51320-3110	Fluid Mech	Cv=1.5 (Fluid Mechanics)	L212
RV0206	Helium Supply Relief Valve - Model	He	730	530	0.5	0.26	51320-3110	Fluid Mech	Cv=1.5 (Fluid Mechanics);Set 810 psi	L212
SV0201	Helium Tank Shutoff Valve - Model	He	10000	530	0.375	0.09	KS14525	Keane	Part of Manifold 3254744;A=0.006in^2	L201
SV0202	Helium Tank Shutoff Valve - Model	He	10000	530	0.375	0.09	KS14525	Keane	Part of Manifold 3254744;A=0.006in^2	L201
SV0203	Helium Tank Shutoff Valve - Model	He	10000	530	0.375	0.09	KS14525	Keane	Part of Manifold 3254742-1;A=0.006in^2	L201
SV0205	T-TEB Purge Shutoff Valve	He	730	530	0.5	96 SCFM	3254770-1	Allied/Keane	Part of TEA-TEB Press;A=0.006in^2	L207
SV0206	Helium Tank Shutoff Valve - Canoe	He	10000	530	0.375	0.09	KS14667	Keane	Part of Manifold 3254742-2;A=0.006in^2	L202
SV0208	Helium Tank Shutoff Valve - Canoe	He	10000	530	0.375	0.09	KS14667	Keane	Part of Manifold 3254743;A=0.006in^2	L202
SV0209	T-TEB Tank#1 Pressurization Shutoff Valve	He	730	530	0.5	96 SCFM	3254770-1	Allied/Keane	Part of TEA-TEB Press;A=0.006in^2	L206
SV0210	T-TEB Trickle Purge Shutoff Valve	He	730	530	0.5	40SCIM	3254770-1	Allied/Keane	Part of TEA-TEB Press;A=0.006in^2	L208
SV0211	Helium Tank Shutoff Valve - Canoe	He	10000	530	0.375	0.09	KS14667	Keane	Part of Manifold 3254743;A=0.006in^2	L202
SV0212	T-TEB Tank#2 Pressurization Shutoff Valve	He	730	530	0.25	96 SCFM	KS14637-1	Keane	A=0.006in^2	L206
TC0201	Helium Tank Thermocouple - Model	He	10000	530	N/A	N/A			Type K Thermocouple	N/A
TC0202	Helium Tank Thermocouple - Model	He	10000	530	N/A	N/A			Type K Thermocouple	N/A
TC0203	Helium Tank Thermocouple - Canoe	He	10000	530	N/A	N/A			Type K Thermocouple	N/A
TC0204	Helium Tank Thermocouple - Canoe	He	10000	530	N/A	N/A			Type K Thermocouple	N/A
TC0206	Helium Tank Thermocouple - Canoe	He	10000	530	N/A	N/A			Type K Thermocouple	N/A
TK0201	Helium Tank - Model	He	10000	530	0.375	0.09	Part of 3269626-1	Allied	dia=15"	N/A
TK0202	Helium Tank - Model	He	10000	530	0.375	0.09	Part of 3269626-1	Allied	dia=15"	N/A
TK0203	Helium Tank - Canoe	He	10000	530	0.375	0.09	Part of 3269626-1	Allied	dia=15"	N/A
TK0204	Helium Tank - Canoe	He	10000	530	0.375	0.09	Part of 3269626-1	Allied	dia=15"	N/A
TK0206	Helium Tank - Canoe	He	10000	530	0.375	0.09	Part of 3269626-1	Allied	dia=15"	N/A
Vehicle Water Subsystem										
CV0401	H2O Tank Pressurization Check Valve	He	800	530	0.75	0.27	220T-12JJ	Circle Seal		L202
CV0402	H2O Tank Pressurization Check Valve	He	800	530	0.75	0.27	220T-12JJ	Circle Seal		L202
MV0401	H2O Tank Overflow/Vent Valve	H2O	800	530	0.5	0.5	81875-8KR	Dragon		L404
MV0402	H2O Tank Overflow/Vent Valve	H2O	800	530	0.5	0.5	81875-8KR	Dragon		L404
MV0403	H2O Tank Fill Valve	H2O	800	530	0.5	0.5	81875-8KR	Dragon		L405
OR0404	Engine Cooldown Orifice	H2O	800	530	0.375	2	AA1634-6K	Allen Aircraft	017" Drill	L403
PT0401	H2O Tank Pressure Transducer	H2O	800	530	0.25	N/A	AP122CV-1e-2c-5d-9b	Sensotec	0-1000 PSIA, Model TJE/A578-01-01	L401
PV0401	H2O Shut-off Valve	H2O	800	530	1.5	40	3269638	Allied		L401
PV0402	Water Tank Pressurization Valve	He	1250	530	0.75	0.27	KP14665	Keane	Cv=2.295	L202
PV0403	Water Tank Pressurization Valve	He	1250	530	0.75	0.27	KP14665	Keane	Cv=2.295	L202
RV0401	H2O Tank Relief Valve	He	800	530	0.5	0.27	5120T-8TJ-800	Circle Seal		L406
RV0402	H2O Tank Relief Valve	He	800	530	0.5	0.27	5120T-8TJ-800	Circle Seal		L406
SV0401	PV0403 Control Valve	He	1250	530	0.25	N/A	KS14655	Keane		L202
SV0402	PV0402 Control Valve	He	1250	530	0.25	N/A	KS14655	Keane		L202
SV0403	Engine Cooldown Valve	H2O	800	530	0.375	2	15810	Atkomatic		L403
TK0401	H2O Tank	H2O	800	530	1.5	20	P92196C-2	ARDE	Note 7	L401
TK0402	H2O Tank	H2O	800	530	1.5	20	P92196C-2	ARDE	Note 7	L401

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Table 6. LASRE propulsion system parts list (Continued).

LASRE Propulsion System Parts List

9/22/97

Ref Des	Nomenclature	Fluid	Pressure (psia)	Temp (oR)	Line Size (in)	Flow rate (#/s)	Part No.	Supplier	Notes	Line No.
Vehicle Oxygen Subsystem										
CV0301	LO2 Engine Feed Line Purge Check Valve	GHe/GO2	700	162-530	0.5	200SCFM	K220T-8JJ	Circle Seal		L204
CV0302	LO2 Engine Feed Line Purge Check Valve	GHe/GO2	700	162-530	0.5	200SCFM	K220T-8JJ	Circle Seal		L204
CV0303	LO2 Tank Pressurization Check Valve	GHe/GO2	700	162-530	0.75	0.26	K220T-12JJ	Circle Seal		L201
CV0304	LO2 Tank Pressurization Check Valve	GHe/GO2	700	162-530	0.75	0.26	K220T-12JJ	Circle Seal		L201
CV0305	LO2 Tank Pressure Control Check Valve	GHe/GO2	20	162-530	0.5	0.0017	K220T-8JJ-5	Circle Seal	5 psid Crack Pressure	L306
CV0306	LO2 Interstitial Seal Vent Check Valve	GO2	65	530	0.25	N/A	220T-4JJ	Circle Seal		L303
CV0307	Oxygen Tank Overflow Port Check Valve	LO2	700	160-190	1	0.3	K220T-12JJ	Circle Seal		L304
LS0301	LO2 Level Sensor - Low	LO2	700	162-530	N/A	N/A			Type E Thermocouple	N/A
LS0302	LO2 Level Sensor - Top	LO2	700	162-530	N/A	N/A			Type E Thermocouple	N/A
LS0303	LO2 Level Sensor - Full	LO2	700	162-530	N/A	N/A			Type E Thermocouple	N/A
LS0304	LO2 Level Sensor - Overfull	LO2	700	162-530	N/A	N/A			Type E Thermocouple	N/A
MV0301	LO2 Fill/Drain Valve	LO2	700	162-530	0.5	0.3	V-1060-050	CVI		L302
MV0302	LO2 Flight Tank Fill Vent Valve	GO2	700	162-530	0.5	0.3	V-1060-050	CVI		L304
MV0303	LO2 Tank Back Pressure Reg Blocking Valve	GHe/GO2	700	162-530	0.5	0.0017	V-1060-050	CVI		L306
OR0301	LO2 Flight Tank Vent Orifice	GO2	65	162-530	0.375	0.3	AA1634-6K	Allen Aircraft	0.19" Drill	L303
OR0302	LO2 Engine Feed Line Purge Orifice	GHe	700	530	0.5	200SCFM	AA1634-8K	Allen Aircraft	0.2" Drill	L204
OR0303	LO2 Engine Chilldown Orifice	LO2	700	162-530	0.375	2	Conical Seal Orifice	N/A	0.24" Drill	L305
OR0304	LO2 Tank Pressurization Orifice	GHe	700	530	0.75	0.3	AA1634-12K	Allen Aircraft	0.30" Drill	L303
PT0301	LO2 Flight Tank Pressure 1	LO2	0-1000	162-530	0.25	N/A	AP122CV-1e-2c-5d-9b	Sensotec	0-1000 PSIA, Model TJE/A578-01-01	N/A
PT0302	LO2 Flight Tank Pressure 2	LO2	0-1000	162-530	0.25	N/A	AP122CV-1e-2c-5d-9b	Sensotec	0-1000 PSIA, Model TJE/A578-01-01	N/A
PT0303	LO2 Flight Tank Pressure Transducer	LO2	0-1000	162-530	0.25	N/A	AP122CV-1e-2c-5d-9b	Sensotec	Monitored from Cockpit, 0-1000 PSIA, Model TJE/A578-01-01	N/A
PV0301	LO2 Engine Feed Valve	LO2	700	162-530	1.5	14.5	3269638	Allied		L301
PV0304	LO2 Tank Pressurization Valve	GHe	700	530	0.75	0.26	KP14665	Keane	Cv=2.295	L201
RV0301	LO2 Flight Tank Relief Valve	GHe/GO2	700	162-530	0.5	0.3	K5120T-8TJ-800	Circle Seal		L303
SV0301	LO2 Flight Tank Vent Valve	GO2	Set 770	162-530	0.375	0.3	15810	Atkomatic		L303
SV0302	LO2 Engine Chilldown Valve	LO2	700	162-530	0.375	2	31800	Atkomatic	Cv=1.1	L305
SV0303	LO2 Engine Feed Line Purge Valve	GHe	700	162-530	0.5	200SCFM	KS14709	Keane	A=0.006in^2	L204
SV0304	PV0304 Control Valve	GHe	700	530	0.25	N/A	KS14655	Keane		L201
TK0301	LASRE LO2 Propellant Tank	LO2	700	162-530	1.5	14.5	P92196C-1	ARDE	Note 7	L301

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Table 7. LASRE interface list.

Interface	Nomenclature	From	To	Fluid	Pressure (psig)	Temp (oR)	Line Size (in)	Flow rate (#/s)	Prop System Interface	Notes
Vehicle Hydrogen Subsystem										
GH-ENG-001	Hydrogen Supply to Engine	GH2 System	Engine	GH2	600	380-530	1.5	2.42	Ring Seal	
GH-GND-001	Hydrogen Fill & Vent	Ground	GH2 System	GH2	6000	530	0.5	0.015	Snap-tite SH71-1N6-8F	Ground Side Mating Quick Disconnect - Snap-tite SH71-1C6-8F
GH-GND-002	Hydrogen Vent	GH2 System	Ground	GH2	720	530	2	6.5	MS33649-32	
GH-GND-003	Hydrogen Quick Disconnect Vent	GH2 System	Ground	GH2	6000	530	0.5	N/A	Ring Seal	
GH-GND-004	Hydrogen Regulator Seal Vent	GH2 System	Ground	GH2	15	530	0.25	1 SCIM	Ring Seal	
Vehicle Oxygen Subsystem										
LO-ENG-001	Liquid Oxygen Supply to Engine	LO2 System	Engine	LO2	600	160-190	1.5	14.5	Ring Seal	
LO-GND-001	LO2 Fill & Drain	Ground	LO2 System	LO2	50	160-190	0.5	0.3	Ring Seal	
LO-GND-002	Oxygen Vent	LO2 System	Ground	GO2	50	160-190	1	0.3	MS33649-16	Exits at top, rear of Model
LO-GND-003	Oxygen Tank Overflow Port	LO2 System	Ground	LO2	50	160-190	1	0.3	Ring Seal	Note 8
Vehicle Helium Subsystem										
HE-ENG-001	TEA-TEB Tank#1 Pressurization	GHe System	Engine	GHe	730	530	0.25	96 SCFM	Tubing Flare	
HE-ENG-002	TEA-TEB Tank#2 Pressurization	GHe System	Engine	GHe	730	530	0.25	96 SCFM	Tubing Flare	
HE-ENG-003	TEA-TEB Trickle Purge	GHe System	Engine	GHe	730	530	0.25	40 SCIM	Tubing Flare	
HE-ENG-004	TEA-TEB Purge	GHe System	Engine	GHe	730	530	0.25	96 SCFM	Tubing Flare	
HE-GND-001	Helium Fill - Model	Ground	GHe System	GHe	10000	530	0.375	0.0024	Ring Seal	
HE-GND-002	Helium Fill - Canoe	Ground	GHe System	GHe	10000	530	0.375	0.0036	Ring Seal	
HE-GND-003	He Vent - Model Bottom	GHe System	Ground	GHe	200	530	0.75	0.41	No fitting	Exits between Model and Canoe
HE-GND-004	Helium Vent - Canoe	GHe System	Ground	GHe	200	530	0.75	0.41	No fitting	
HE-GND-005	He Vent - Model Top	GHe System	Ground	GHe	200	530	0.75	0.26	No fitting	Exits at top, rear of Model
HE-GND-006	TEA-TEB Helium Safing Vent	Ground	GHe System	GHe	730	530	0.375	N/A	Ring Seal	Cap for Flight
Vehicle Water Subsystem										
H2O-ENG-001	Water Supply to Engine	Water System	Engine	H2O	600	530	1.5	40	Ring Seal	
H2O-ENG-002	Water Return from Engine	Engine	Water System	H2O	200	710 max	1.5	40	Ring Seal	
H2O-GND-001	Water Fill	Ground	Water System	H2O	800	530	0.5	0.5	Ring Seal	
H2O-GND-002	Water Tank Over-fill 1	Water System	Ground	H2O	N/A	530	0.5	0.5	Ring Seal	
H2O-GND-003	Water Tank Over-fill 2	Water System	Ground	H2O	N/A	530	0.5	0.5	Ring Seal	
H2O-GND-004	Water Tank Relief Valve Vent	Water System	Ground	GHe	275	530	0.5	0.32	No fitting	
H2O-GND-005	Water Overboard Dump	Water System	Ground	H2O	200	710 max	1.5	40	MS33649-24	
Vehicle TEA-TEB Subsystem										
TT-GND-001	TEA-TEB Manual Purge	Ground	Engine	GN2/TT	730	530	0.25	N/A	Tubing flare	20 psi GN2 purge
TT-GND-002	TEA-TEB Contingency Vent	TT System	Ground	GHe/TT	730	530	0.25	N/A	Tubing flare	

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APPENDIX D—Instrumentation List

The LASRE program master measurement list is shown in table 8.

Table 8. LASRE program master measurement list.

NASA/LMSW LASRE Program Master Measurement List
Revision P Date 04/03/98

CIMS ID /	Sys Sch				Range		Eng.		Transducer		Transducer		Instru'n	Installed
Meas. #	Ref Des	LOC	Parameter Description	Dwg #	Min	Max	Units	Critical	Mfg.	Serial #	Type	Status	Respon	By:
BP001	EMERSS	S	Cockpit Emergency Shutoff Switch	5405	0	36	Volt					Cal 03/08/96	LMSW	LMSW
MX09	MX09B06	CS	Contr. Status, SV0203 Open		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX09	MX09B07	CS	Contr. Status, SV0202 Open		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX09	MX09B08	CS	Contr. Status, SV0201 Open		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX09	MX09B10	CS	Contr. Status, SV0102 Open		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX09	MX09B11	CS	Contr. Status, SV0101 Open		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX09	MX09B12	CS	Contr. Status, LO2 Clutch Engaged		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX10	MX10B06	CS	Contr. Status, SV0211 Open		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX10	MX10B07	CS	Contr. Status, SV0210 Open		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX10	MX10B08	CS	Contr. Status, SV0209 Open		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX10	MX10B09	CS	Contr. Status, SV0208 Open		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX10	MX10B10	CS	Contr. Status, SV0212 Open		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX10	MX10B11	CS	Contr. Status, SV0206 Open		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX10	MX10B12	CS	Contr. Status, SV0205 Open		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX11	MX11B07	CS	Contr. Status, SV0403 Open		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX11	MX11B08	CS	Contr. Status, SV0402 Open		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX11	MX11B09	CS	Contr. Status, SV0401 Open		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX11	MX11B10	CS	Contr. Status, SV0304 Open		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX11	MX11B11	CS	Contr. Status, SV0303 Open		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX11	MX11B12	CS	Contr. Status, SV0302 Open		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX12	MX12B05	CS	AS Stat., GH2 Position Ind. Open		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX12	MX12B06	CS	AS Stat., Controller Ready		NO	YES	Discrete				Discrete	Cal 03/12/96	LMSW	N/A
MX12	MX12B07	CS	AS Stat., Internal Volt, In Range		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX12	MX12B08	CS	AS Stat., GH2 Valve Clutch Current		Low	Good	Discrete				Discrete	Operational	LMSW	N/A
MX12	MX12B09	CS	AS Stat., H2O Valve Clutch Current		Low	Good	Discrete				Discrete	Operational	LMSW	N/A
MX12	MX12B10	CS	AS Stat., LO2 Valve Clutch Current		Low	Good	Discrete				Discrete	Operational	LMSW	N/A
MX12	MX12B11	CS	AS Stat., H2O Position Ind. Open		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX12	MX12B12	CS	AS Stat., LO2 Position Ind. Open		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX13	N/A	CS	Contr. Status, Repeat AS H2 Position		0	0.4	INCH				Interger	Cal 03/08/96	LMSW	N/A
MX14	PT0102	CS	Contr. Status, Repeat AS H2 Pressure		0	1,000	PSIA				Interger	Cal 03/08/96	LMSW	N/A
MX15	N/A	CS	AS Stat., GH2 Servoamp Temp.		-10	100	DEG C				Interger	Cal 04/16/96	LMSW	N/A
MX31	MX31B12	CS	Contr. Status, Controller Abort		NO	YES	Discrete				Discrete	Operational	LMSW	N/A
MX33	N/A	CS	Contr. Status, OFP Version, Number		0	4095	Counts				Interger	Operational	LMSW	N/A
MX35	N/A	CS	Contr. Status, GLS Version, Number		0	4095	Counts				Interger	Operational	LMSW	N/A
MX37	N/A	CS	Contr. Status, CIMS Version, Number		0	4095	Counts				Interger	Operational	LMSW	N/A
MX39	N/A	CS	Contr. Status, STable Version, Number		0	4095	Counts				Interger	Operational	LMSW	N/A
MX40	N/A	CS	Contr. Status, STable Timer (Fine)				INTEGER				Interger	Operational	LMSW	N/A
MX41	N/A	CS	Contr. Status, STable Timer (Coarse)				INTEGER				Interger	Operational	LMSW	N/A
MX42	N/A	CS	Contr. Status, Repeat AS LO2 Position		0	100	DEG				Interger	Cal 04/08/96	LMSW	N/A
MX43	N/A	CS	Contr. Status, Repeat AS H2O Position		0	100	DEG				Interger	Cal 04/08/96	LMSW	N/A
MX52	MX52B05	CS	AS Stat., Software Version Number		0	15	Counts				Interger	Cal 05/24/96		

FC = Flight Critical
FS = Flight Safety
MC = Mission Critical
TD = Technically Desirable

Table 8. LASRE program master measurement list (Continued).

NASA/LMSW LASRE Program Master Measurement List
Revision P Date 04/03/98

CIMS ID /	Sys Sch				Range		Eng.		Transducer		Transducer		Instru'n	Installed
Meas. #	Ref Des	LOC	Parameter Description	Dwg #	Min	Max	Units	Critical	Mfg.	Serial #	Type	Status	Respon	By:
MX52	MX52B09	CS	AS Stat., Status Req Dropout Ind.		No	Yes	Discrete				Interger	Cal 03/12/96		
MX52	MX52B10	CS	AS Stat., H2O Valve Command Open		No	Yes	Discrete				Interger	Cal 03/12/96		
MX52	MX52B11	CS	AS Stat., LO2 Valve Command Open		No	Yes	Discrete				Interger	Cal 03/12/96		
MX52	MX52B12	CS	AS Stat., H2 Valve Command Open		No	Yes	Discrete				Interger	Cal 03/12/96		
P31001C	N/A	S	Total Air Pressure, Sonix (Coarse)	012-6	0.25	38	PSIA	MC	PSI		sonix	Cal 06/30/93	DFRC	Existing
P31001F	N/A	S	Total Air Pressure, Sonix (Fine)	012-6	0.25	38	PSIA	MC	PSI		sonix	Operational	DFRC	Existing
P31002C	N/A	S	Static Air Press, Sonix (Coarse)	012-6	0.25	38	PSIA	MC	PSI		sonix	Cal 06/30/93	DFRC	Existing
P31002F	N/A	S	Static Air Press, Sonix (Fine)	012-6	0.25	38	PSIA	MC	PSI		sonix	Operational	DFRC	Existing
PC001	PC001	M	Mist Water System Press	5405/40	0	40	PSIG		Statham	20002	Press (350W)	Cal 11/14/97	LMSW	LMSW
PC002	PC002	S	Nitrogen Purge Sys. Out Press	028-5	0	50	PSIG				Press (350W)	Cal 05/17/96	LMSW	LMSW
PC003	PC003	S	Heat Exch Out Press (Mist H2O)	028-5	0	50	PSIG				Press (350W)	Cal 05/17/96	LMSW	LMSW
PF002	PT0160	M	Press, venturi, 100% GH2, upstream	5403	0	1,000	PSIG		Taber (JPL)	591536	Press (350W)	Cal 03/28/96	LMSW	R/D
PF005	PT0163	M	Press, venturi, 80% GH2, upstream	5403	0	1,000	PSIG		Taber (RD)	742095	Press (350W)	Cal 02/24/97	LMSW	R/D
PF006	PT0360	M	Press, venturi, 100% LOX, upstream	5403	0	1,000	PSIA		Statham	3764	Press (350W)	Cal 03/28/96	LMSW	R/D
PF007	PT0361	M	Press, venturi, 20% LOX, Downstream	5403	0	1,000	PSIA		Statham	3745	Press (350W)	Cal 03/28/96	LMSW	R/D
PF008	PT0362	M	Press, venturi, 80% LOX, Downstream	5403	0	1,000	PSIA		Statham	3754	Press (350W)	Cal 03/28/96	LMSW	R/D
PF009	PT0363	M	Press, venturi, 80% LOX, upstream	5403	0	1,000	PSIA		Statham	3751	Press (350W)	Cal 03/28/96	LMSW	R/D
PF010	PT0152	M	Press, GH2 Injector Inlet (TH001)	5401	0	500	PSIG		Taber (JPL)	691592	Press (350W)	Cal 03/28/96	LMSW	R/D
PF011	PT0153	M	Press, GH2 Injector Inlet (TH002)	5401	0	1,000	PSIG		Taber (JPL)	602241	Press (350W)	Cal 03/28/96	LMSW	R/D
PF012	PT0154	M	Press, GH2 Injector Inlet (TH003)	5401	0	1,000	PSIG		Taber (JPL)	662508	Press (350W)	Cal 03/28/96	LMSW	R/D
PF013	PT0155	M	Press, GH2 Injector Inlet (TH004)	5401	0	500	PSIG		Taber (JPL)	613661	Press (350W)	Cal 03/28/96	LMSW	R/D
PF014	PT0156	M	Press, GH2 Injector Inlet (TH005)	5401	0	1,000	PSIG		Taber (RD)	820216	Press (350W)	Cal 04/14/96	LMSW	R/D
PF015	PT0157	M	Press, GH2 Injector Inlet (TH006)	5401	0	1,000	PSIG		Taber (JPL)	641663	Press (350W)	Cal 03/28/96	LMSW	R/D
PF016	PT0158	M	Press, GH2 Injector Inlet (TH007)	5401	0	1,000	PSIG		Taber (JPL)	662509	Press (350W)	Cal 03/28/96	LMSW	R/D
PF017	PT0159	M	Press, GH2 Injector Inlet (TH008)	5401	0	1,000	PSIG		Taber (JPL)	662601	Press (350W)	Cal 03/28/96	LMSW	R/D
PF018	PT0352	M	Press, LOX Injector Inlet (TH001)	5401	0	1,000	PSIA		Statham	3756	Press (350W)	Cal 03/28/96	LMSW	R/D
PF019	PT0353	M	Press, LOX Injector Inlet (TH002)	5401	0	1,000	PSIA		Statham	3743	Press (350W)	Cal 03/28/96	LMSW	R/D
PF020	PT0354	M	Press, LOX Injector Inlet (TH003)	5401	0	1,000	PSIG		Taber (JPL)	662514	Press (350W)	Cal 03/28/96	LMSW	R/D
PF021	PT0355	M	Press, LOX Injector Inlet (TH004)	5401	0	1,000	PSIA		Statham	3746	Press (350W)	Cal 09/20/96	LMSW	R/D
PF022	PT0356	M	Press, LOX Injector Inlet (TH005)	5401	0	1,000	PSIA		Statham	3749	Press (350W)	Cal 03/28/96	LMSW	R/D
PF023	PT0357	M	Press, LOX Injector Inlet (TH006)	5401	0	1,000	PSIA		Statham	3744	Press (350W)	Cal 03/28/96	LMSW	R/D
PF024	PT0358	M	Press, LOX Injector Inlet (TH007)	5401	0	1,000	PSIG		Taber (JPL)	662511	Press (350W)	Cal 12/12/96	LMSW	R/D
PF025	PT0359	M	Press, LOX Injector Inlet (TH008)	5401	0	1,000	PSIA		Statham	3758	Press (350W)	Cal 03/28/96	LMSW	R/D
PF026	PT0301	M	LOX Flight Tank Pressure 1	5430	0	1,000	PSIA		Sensotech	496648	Press, H/L	Cal 03/26/96	LMSW	LMA
PF027	PT0302	M	LOX Flight Tank Pressure 2	5430	0	1,000	PSIA		Sensotech	496647	Press, H/L	Cal 03/26/96	LMSW	LMA
PF028	PT0201	M	He Tank Press (LOX Sys.)	5420	0	15,000	PSIA		Sensotech	608891	Press, H/L	Cal 07/22/97	LMSW	LMA
PF029	PT0202	M	He Supply Press (TTEB Sys.)	5420	0	1,000	PSIA		Sensotech	499025	Press, H/L	Cal 02/20/96	LMSW	LMA
PF030	PT0101	M	GH2 Tank Press	5405/10	0	10,000	PSIA		Sensotech	616763	Press, H/L	Cal 07/22/97	LMSW	LMA
PF032	PT0203	M	He Tank Press (H2O Sys.)	5405/21	0	15,000	PSIA		Sensotech		Press, H/L	Cal 02/29/96	LMSW	LMA

FC = Flight Critical
FS = Flight Safety
MC = Mission Critical
TD = Technically Desirable

Table 8. LASRE program master measurement list (Continued).

NASA/LMSW LASRE Program Master Measurement List
Revision P Date 04/03/98

CIMS ID / Meas. #	Sys Sch Ref Des	LOC	Parameter Description	Dwg #	Range Min	Range Max	Eng. Units	Critical	Transducer Mfg.	Transducer Serial #	Transducer Type	Status	Instru'n Respon	Installed By:
PF033	PT0210	M	He Supply Press (H2O Sys.)	5405/21	0	1,500	PSIA		Statham	3938	Press (350W)	Cal 04/26/96	LMSW	LMA
PF034	PT0651	M	TTEB Manifold Press	5403	0	1,000	PSIA		Statham	3750	Press (350W)	Cal 12/12/96	LMSW	R/D
PF036	PT0205	M	He Supply Press (LOX Sys.)	5420	0	1,000	PSIA		Sensotech	499030	Press, H/L	Cal 03/12/96	LMSW	LMA
PF041	PT0207	M	LO2 Feed Line Purge Press	5420	0	750	PSIA		Sensotech	462346	Press, H/L	Cal 04/08/96	LMSW	
PF042	PT0208	M	TTEB Trickle Purge Press	5420	0	1,000	PSIA		Sensotech	496658	Press, H/L	Cal 04/08/96	LMSW	
PF045	PT0104	M	GH2 Engine Purge Press	5405/10	0	1,500	PSIA		Statham	1723	Press (350W)	Cal 12/12/96	LMSW	
PF046	PT0164	M	Press, venturi, 20% GH2, upstream	5403		1,000	PSIG		Taber (JPL)	662513	Press (350W)	Cal 12/12/96	LMSW	R/D
PF047	PT0364	M	Press, venturi, 20% LOX, upstream	5403	0	1,000	PSIA		Statham	1695A	Press (350W)	Cal 03/28/96	LMSW	R/D
POXY01	N/A	C	Partial Pressure Oxygen #01		0	3.1	PSIA	TD	Teledyne	204	02 Sensor	Cal 02/05/98	DFRC	DFRC
POXY02	N/A	C	Partial Pressure Oxygen #02		0	3.1	PSIA	TD	Teledyne	182	02 Sensor	Cal 02/05/98	DFRC	DFRC
POXY03	N/A	C	Partial Pressure Oxygen #03		0	3.1	PSIA	TD	Teledyne	181	02 Sensor	Cal 02/05/98	DFRC	DFRC
POXY04	N/A	C	Partial Pressure Oxygen #04		0	3.1	PSIA	TD	Teledyne	195	02 Sensor	Cal 02/05/98	DFRC	DFRC
POXY05	N/A	C	Partial Pressure Oxygen #05		0	3.1	PSIA	TD	Teledyne	188	02 Sensor	Cal 02/05/98	DFRC	DFRC
POXY06	N/A	C	Partial Pressure Oxygen #06		0	3.1	PSIA	TD	Teledyne	191	02 Sensor	Cal 02/05/98	DFRC	DFRC
POXY07	N/A	C	Partial Pressure Oxygen #07		0	3.1	PSIA	TD	Teledyne	193	02 Sensor	Cal 02/05/98	DFRC	DFRC
POXY08	N/A	C	Partial Pressure Oxygen #08		0	3.1	PSIA	TD	Teledyne	199	02 Sensor	Cal 02/05/98	DFRC	DFRC
POXY09	N/A	M	Partial Pressure Oxygen #09		0	3.1	PSIA	TD	Teledyne	180	02 Sensor	Cal 02/05/98	DFRC	DFRC
POXY10	N/A	M	Partial Pressure Oxygen #10		0	3.1	PSIA	TD	Teledyne	186	02 Sensor	Cal 02/05/98	DFRC	DFRC
POXY11	N/A	M	Partial Pressure Oxygen #11		0	3.1	PSIA	TD	Teledyne	197	02 Sensor	Cal 02/05/98	DFRC	DFRC
POXY12	N/A	M	Partial Pressure Oxygen #12		0	3.1	PSIA	TD	Teledyne	201	02 Sensor	Cal 02/05/98	DFRC	DFRC
PP025	PT0453	M	H2O Outlet Pres. #1	5403	0	1,000	PSIA		Statham	3201	Press (350W)	Cal 03/27/96	LMSW	
PP027	N/A	M	Ramp Wall Static #1		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP028	N/A	M	Ramp Wall Static #2		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP029	N/A	M	Ramp Wall Static #3		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP030	N/A	M	Ramp Wall Static #4		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP035	N/A	M	Ramp Wall Static #9		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP036	N/A	M	Ramp Wall Static #10		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP037	N/A	M	Ramp Wall Static #11		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP038	N/A	M	Ramp Wall Static #12		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP039	N/A	M	Ramp Wall Static #13		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP040	N/A	M	Ramp Wall Static #14		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP041	N/A	M	Ramp Wall Static #15		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP042	N/A	M	Ramp Wall Static #16		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP043	N/A	M	Ramp Wall Static #17		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP044	N/A	M	Ramp Wall Static #18		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP045	N/A	M	Ramp Wall Static #19		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP046	N/A	M	Ramp Wall Static #20		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP047	N/A	M	Ramp Wall Static #21		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP048	N/A	M	Ramp Wall Static #22		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	

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TD = Technically Desirable

Table 8. LASRE program master measurement list (Continued).

NASA/LMSW LASRE Program Master Measurement List
Revision P Date 04/03/98

CIMS ID /	Sys Sch				Range		Eng.		Transducer		Transducer		Instru'n	Installed
Meas. #	Ref Des	LOC	Parameter Description	Dwg #	Min	Max	Units	Critical	Mfg.	Serial #	Type	Status	Respon	By:
PP049	N/A	M	Ramp Wall Static #23		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP050	N/A	M	Ramp Wall Static #24		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP051	N/A	M	Ramp Wall Static #25		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP052	N/A	M	Ramp Wall Static #26		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP053	N/A	M	Ramp Wall Static #27		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP054	N/A	M	Ramp Wall Static #28		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP055	N/A	M	Ramp Wall Static #29		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP056	N/A	M	Ramp Wall Static #30		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP057	N/A	M	Ramp Wall Static #31		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP058	N/A	M	Ramp Wall Static #32		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP059	N/A	M	Ramp Wall Static #33		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP060	N/A	M	Ramp Wall Static #34		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP061	N/A	M	Ramp Wall Static #35		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP062	N/A	M	Ramp Wall Static #36		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP063	N/A	M	Ramp Wall Static #37		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP064	N/A	M	Ramp Wall Static #38		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP065	N/A	M	Ramp Wall Static #39		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP066	N/A	M	Ramp Wall Static #40		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP067	N/A	M	Ramp Wall Static #41		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP068	N/A	M	Ramp Wall Static #42		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP069	N/A	M	Ramp Wall Static #43		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP070	N/A	M	Ramp Wall Static #44		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP071	N/A	M	Ramp Wall Static #45		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP072	N/A	M	Ramp Wall Static #46		-50	50	PSID		PSI		ESP 64HD	Cal 02/25/97	LMSW	
PP100	PT0001	M	Chamber Press (TH001)	5401	0	500	PSIG		Taber (JPL)	613668	Press (350W)	Cal 03/28/96	LMSW	
PP101	PT0002	M	Chamber Press (TH002)	5401	0	500	PSIG		Taber (JPL)	631561	Press (350W)	Cal 03/28/96	LMSW	
PP102	PT0003	M	Chamber Press (TH003)	5401	0	500	PSIG		Taber (JPL)	631563	Press (350W)	Cal 03/28/96	LMSW	
PP103	PT0004	M	Chamber Press (TH004)	5401	0	500	PSIG		Taber (JPL)	625997	Press (350W)	Cal 03/28/96	LMSW	
PP104	PT0005	M	Chamber Press (TH005)	5401	0	500	PSIG		Taber (JPL)	624871	Press (350W)	Cal 03/28/96	LMSW	
PP105	PT0006	M	Chamber Press (TH006)	5401	0	500	PSIG		Taber (JPL)	800531	Press (350W)	Cal 03/28/96	LMSW	
PP106	PT0007	M	Chamber Press (TH007)	5401	0	500	PSIG		Taber (JPL)	800453	Press (350W)	Cal 03/28/96	LMSW	
PP107	PT0008	M	Chamber Press (TH008)	5401	0	500	PSIG		Taber (JPL)	626001	Press (350W)	Cal 03/28/96	LMSW	
PP108	PT0451	M	H2O Inlet Press #1	5403	0	1,500	PSIA		Statham	3942	Press (350W)	Cal 12/05/96	LMSW	
PP110	PT0401	M	H2O Tank Press	5440/69	0	1,000	PSIA		Sensotech	496651	Press, H/L	Cal 04/17/96	LMSW	
PP111	N/A	M	Fence Static #1		-50	50	PSID				ESP 64HD	Cal 02/25/97	LMSW	
PP112	N/A	M	Fence Static #2		-50	50	PSID				ESP 64HD	Cal 02/25/97	LMSW	
PP113	N/A	M	Fence Static #3		-50	50	PSID				ESP 64HD	Cal 02/25/97	LMSW	
PP114	N/A	M	Fence Static #4		-50	50	PSID				ESP 64HD	Cal 02/25/97	LMSW	
PP115	N/A	M	Fence Static #5		-50	50	PSID				ESP 64HD	Cal 02/25/97	LMSW	

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Table 8. LASRE program master measurement list (Continued).

NASA/LMSW LASRE Program Master Measurement List
Revision P Date 04/03/98

CIMS ID /	Sys Sch				Range		Eng.		Transducer				Instru'n	Installed
Meas. #	Ref Des	LOC	Parameter Description	Dwg #	Min	Max	Units	Critical	Mfg.	Serial #	Type	Status	Respon	By:
PP116	N/A	M	Fence Static #6		-50	50	PSID				ESP 64HD	Cal 02/25/97	LMSW	
PP117	N/A	M	Fence Static #7		-50	50	PSID				ESP 64HD	Cal 02/25/97	LMSW	
PP118	N/A	M	Fence Static #8		-50	50	PSID				ESP 64HD	Cal 02/25/97	LMSW	
PP119	N/A	M	Fence Static #9		-50	50	PSID				ESP 64HD	Cal 02/25/97	LMSW	
PP120	N/A	M	Fence Static #10		-50	50	PSID				ESP 64HD	Cal 02/25/97	LMSW	
PP121	N/A	M	Fence Static #11		-50	50	PSID				ESP 64HD	Cal 02/25/97	LMSW	
PP122	N/A	M	Fence Static #12		-50	50	PSID				ESP 64HD	Cal 02/25/97	LMSW	
PP123	N/A	M	Fence Static #13		-50	50	PSID				ESP 64HD	Cal 02/25/97	LMSW	R/D
PP124	N/A	M	Fence Static #14		-50	50	PSID				ESP 64HD	Cal 02/25/97	LMSW	R/D
TA41001	N/A	S	Total Temperature	012-2	-58	921	DEG F	MC			Hades	Cal 03/23/96	DFRC	Existing
TB043	N/A	M	Temp, Ambient air in Balance	5409	-65	1235	DEG F	TBD			TC, Cr-Al	Cal 04/18/96	LMSW	LMSW
TB074	N/A	M	Temp, Model Air (Cockpit)		32	250	DEG F				TC, Cr-Al	Installed		
TC001	TC001	S	Temp, Cooling Water Out Flow	028-5	17	280	DEG F				TC, Cr-Al	Cal 05/17/96		
TC002	TC002	S	Temp, Cooling Water Return	028-5	17	280	DEG F				TC, Cr-Al	Cal 05/17/96		
TF001	TT0651	M	TTEB Manifold Temp	5404	-338	430	DEG F				TC, Cr-Al	Cal 12/09/96	LMSW	R/D
TF002	TT0160	M	GH2, 100% Venturi Inlet Temp.	5404	-338	430	DEG F				TC, Cr-Al	Cal 12/06/96	LMSW	
TF005	TT0163	M	GH2, 80% Venturi Inlet Temp.	5404	-338	430	DEG F				TC, Cr-Al	Cal 12/06/96	LMSW	
TF008	TT0360	M	LOX, 100% Venturi Inlet Temp.	5404	-338	430	DEG F				TC, Cr-Al	Cal 12/09/96	LMSW	
TF011	TT0363	M	LOX, 80% Venturi Inlet Temp.	5404	-338	430	DEG F				TC, Cr-Al	Cal 08/13/96	LMSW	
TF014	TT0152	M	GH2 Injector Inlet Temp. (TH001)	5404	-338	430	DEG F				TC, Cr-Al	Cal 12/06/96	LMSW	
TF018	TT0156	M	GH2 Injector Inlet Temp. (TH005)	5404	-338	430	DEG F				TC, Cr-Al	Cal 12/06/96	LMSW	
TF022	TT0352	M	LOX Injector Inlet Temp. (TH001)	5404	-338	430	DEG F				TC, Cr-Al	Cal 12/06/96	LMSW	
TF023	TT0353	M	LOX Injector Inlet Temp. (TH002)	5404	-338	430	DEG F				TC, Cr-Al	Cal 12/06/96	LMSW	
TF024	TT0354	M	LOX Injector Inlet Temp. (TH003)	5404	-338	430	DEG F				TC, Cr-Al	Cal 12/06/96	LMSW	
TF025	TT0355	M	LOX Injector Inlet Temp. (TH004)	5404	-338	430	DEG F				TC, Cr-Al	Cal 12/06/96	LMSW	
TF027	TT0357	M	LOX Injector Inlet Temp. (TH006)	5404	-338	430	DEG F				TC, Cr-Al	Cal 12/06/96	LMSW	
TF029	TT0359	M	LOX Injector Inlet Temp. (TH008)	5404	-338	430	DEG F				TC, Cr-Al	Cal 12/06/96	LMSW	
TF032	LS0301	M	LOX Level Sensor - Low	5430	-338	390	DEG F				TC, Cr-Al	Cal 04/26/96	LMSW	
TF033	LS0302	M	LOX Level Sensor - Top	5430	-338	390	DEG F				TC, Cr-Al	Cal 04/26/96	LMSW	
TF034	LS0303	M	LOX Level Sensor - Full	5430	-338	390	DEG F				TC, Cr-Al	Cal 04/26/96	LMSW	
TF035	LS0304	M	LOX Level Sensor - O. F.	5430	-338	390	DEG F				TC, Cr-Al	Cal 04/26/96	LMSW	
TF036	TT0164	M	GH2 20% Venturi Inlet Temp.	5404	-338	430	DEG F				TC, Cr-Al	Cal 12/06/96	LMSW	
TF037	TT0364	M	L02 20% Venturi Temp.	5404	-338	430	DEG F				TC, Cr-Al	Cal 12/09/96	LMSW	
TF038	TT0101	C	Temp, Internal, GH2 Tank #1	5422/63	-112	239	DEG F	FC	Scientific Inst.		Temp Probe	Cal 03/08/96		
TF039	TT0102	C	Temp, Internal, GH2 Tank #2	5422/63	-112	239	DEG F	FC	Scientific Inst.		Temp Probe	Cal 03/08/96		
TF040	TT0202	M	Temp, Surface, He Tank (LOX & TTEB)	5420	-338	430	DEG F	FC			TC, Cr-Al	Cal 12/09/96		
TF041	TT0204	C	Temp, Surface, He Tank (H2O System)	5420	-338	430	DEG F	FC			TC, Cr-Al	Cal 12/09/96		
TGEGTL	N/A	S	Exhaust Gas Temp - L/H	028-5	0	1200	DEG C	FC				Cal 05/10/96	DFRC	DFRC
TGEGTR	N/A	S	Exhaust Gas Temp - R/H	028-5	0	1200	DEG C	FC				Cal 05/10/96	DFRC	DFRC

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Table 8. LASRE program master measurement list (Continued).

NASA/LMSW LASRE Program Master Measurement List
Revision P Date 04/03/98

CIMS ID /	Sys Sch				Range		Eng.		Transducer		Transducer		Instru'n	Installed
Meas. #	Ref Des	LOC	Parameter Description	Dwg #	Min	Max	Units	Critical	Mfg.	Serial #	Type	Status	Respon	By:
TOXY01	N/A	C	Temp, Oxygen Sensor #01		-30	180	DEG F	TD	MicroMeas.	12	ETG-50	Cal 08/27/96	DFRC	DFRC
TOXY02	N/A	C	Temp, Oxygen Sensor #02		-30	180	DEG F	TD	MicroMeas.	5	ETG-50	Cal 08/16/96	DFRC	DFRC
TOXY03	N/A	C	Temp, Oxygen Sensor #03		-30	180	DEG F	TD	MicroMeas.	4	ETG-50	Cal 08/16/96	DFRC	DFRC
TOXY04	N/A	C	Temp, Oxygen Sensor #04		-30	180	DEG F	TD	MicroMeas.	7	ETG-50	Cal 08/16/96	DFRC	DFRC
TOXY05	N/A	C	Temp, Oxygen Sensor #05		-30	180	DEG F	TD	MicroMeas.	2	ETG-50	Cal 08/16/96	DFRC	DFRC
TOXY06	N/A	C	Temp, Oxygen Sensor #06		-30	180	DEG F	TD	MicroMeas.	3	ETG-50	Cal 08/16/96	DFRC	DFRC
TOXY07	N/A	C	Temp, Oxygen Sensor #07		-30	180	DEG F	TD	MicroMeas.	1	ETG-50	Cal 08/16/96	DFRC	DFRC
TOXY08	N/A	C	Temp, Oxygen Sensor #08		-30	180	DEG F	TD	MicroMeas.	9	ETG-50	Cal 08/16/96	DFRC	DFRC
TOXY09	N/A	M	Temp, Oxygen Sensor #09		-30	180	DEG F	TD	MicroMeas.	8	ETG-50	Cal 08/16/96	DFRC	DFRC
TOXY10	N/A	M	Temp, Oxygen Sensor #10		-30	180	DEG F	TD	MicroMeas.	11	ETG-50	Cal 08/16/96	DFRC	DFRC
TOXY11	N/A	M	Temp, Oxygen Sensor #11		-30	180	DEG F	TD	MicroMeas.	10	ETG-50	Cal 08/16/96	DFRC	DFRC
TOXY12	N/A	M	Temp, Oxygen Sensor #12		-30	180	DEG F	TD	MicroMeas.	6	ETG-50	Cal 08/16/96	DFRC	DFRC
TP029	TT0451	M	H2O Inlet Temp. #1	5404	-338	430	DEG F				TC, Cr-Al	Cal 04/19/96	LMSW	
TP031	TT0453	M	H2O Outlet Temp. #1	5404	-338	430	DEG F				TC, Cr-Al	Cal 04/19/96	LMSW	
TP033	TT0455	M	H2O R.H. Upper Ramp Outlet Temp	5404	-338	430	DEG F				TC, Cr-Al	Cal 12/09/96	LMSW	
TP034	TT0456	M	H2O R.H. Lower Ramp Outlet Temp	5404	-338	430	DEG F				TC, Cr-Al	Cal 12/09/96	LMSW	
TP035	TT0457	M	H2O L.H. Upper Ramp Outlet Temp	5404	-338	430	DEG F				TC, Cr-Al	Cal 12/09/96	LMSW	
TP036	TT0458	M	H2O L.H. Lower Ramp Outlet Temp	5404	-338	430	DEG F				TC, Cr-Al	Cal 12/09/96	LMSW	
TP037	N/A	M	Calorimeter C1, (engine base plug)	5407	0	100	BTU/FT2		Hy-Cal	30435	TBD	Cal 04/09/97	DFRC	DFRC
TP038	N/A	M	Calorimeter C2, (birdhouse, facing down)	5404	0	120	BTU/FT2		Hy-Cal	73273	TBD	Cal 04/09/97	DFRC	DFRC
TP039	N/A	M	Calorimeter C3, (birdhouse, facing aft)	TBD	0	TBD	BTU/FT2				TBD	Cal 06/27/97	DFRC	DFRC
TP041	N/A	M	Radiometer R2, (birdhouse, facing down)	5404	0	60	BTU/FT2		Hy-Cal	18924	TBD	Cal 04/09/97	DFRC	DFRC
TP042	N/A	M	Radiometer R3, (birdhouse, facing aft)	TBD	0	TBD	BTU/FT2				TBD	Cal 06/27/97	DFRC	DFRC
TP043	N/A	M	Gas Temp Probe G1, (birdhouse, facing aft)	5404	-65	1235	DEG F				TC, Cr-Al	Inoperative	DFRC	DFRC
TP050	N/A	M	Temp, Engine Thrust Chamber OML	5404	-338	430	DEG F				TC, Cr-Al	Cal 06/26/97	LMSW	R/D
TP051	N/A	M	Temp, Engine Thrust Chamber OML	5404	-338	430	DEG F				TC, Cr-Al	Cal 06/26/97	LMSW	R/D
TP052	N/A	M	Temp, Engine Thrust Chamber OML	5404	-338	430	DEG F				TC, Cr-Al	Cal 06/26/97	LMSW	R/D
TP053	N/A	M	Temp, Engine Thrust Chamber OML	5404	-338	430	DEG F				TC, Cr-Al	Cal 06/26/97	LMSW	R/D
TP054	N/A	M	Temp, Engine Thrust Chamber OML	5404	-338	430	DEG F				TC, Cr-Al	Cal 06/26/97	LMSW	R/D

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APPENDIX E—Operating Sequence

Note: States in the test sequence were defined as follows:

Normal operation:

Initialization	in1
Master standby	ms
Prestart	ps1
Start	ss1
Cutoff	co1
Autosafe arm	as1
Autosafe GH_2	as2
Autosafe LO_2	as3
Autosafe H_2O	as4
Mission complete standby	mcs

(Although numbered in series, the autosafe procedures could be performed in any sequence. Generally, as2 (GH_2) and as4 (H_2O) were performed before as3 (LO_2).)

Abort procedures:

Master abort sequence	mas
Master abort hold	mah

The LASRE test sequence is shown in figure 16.

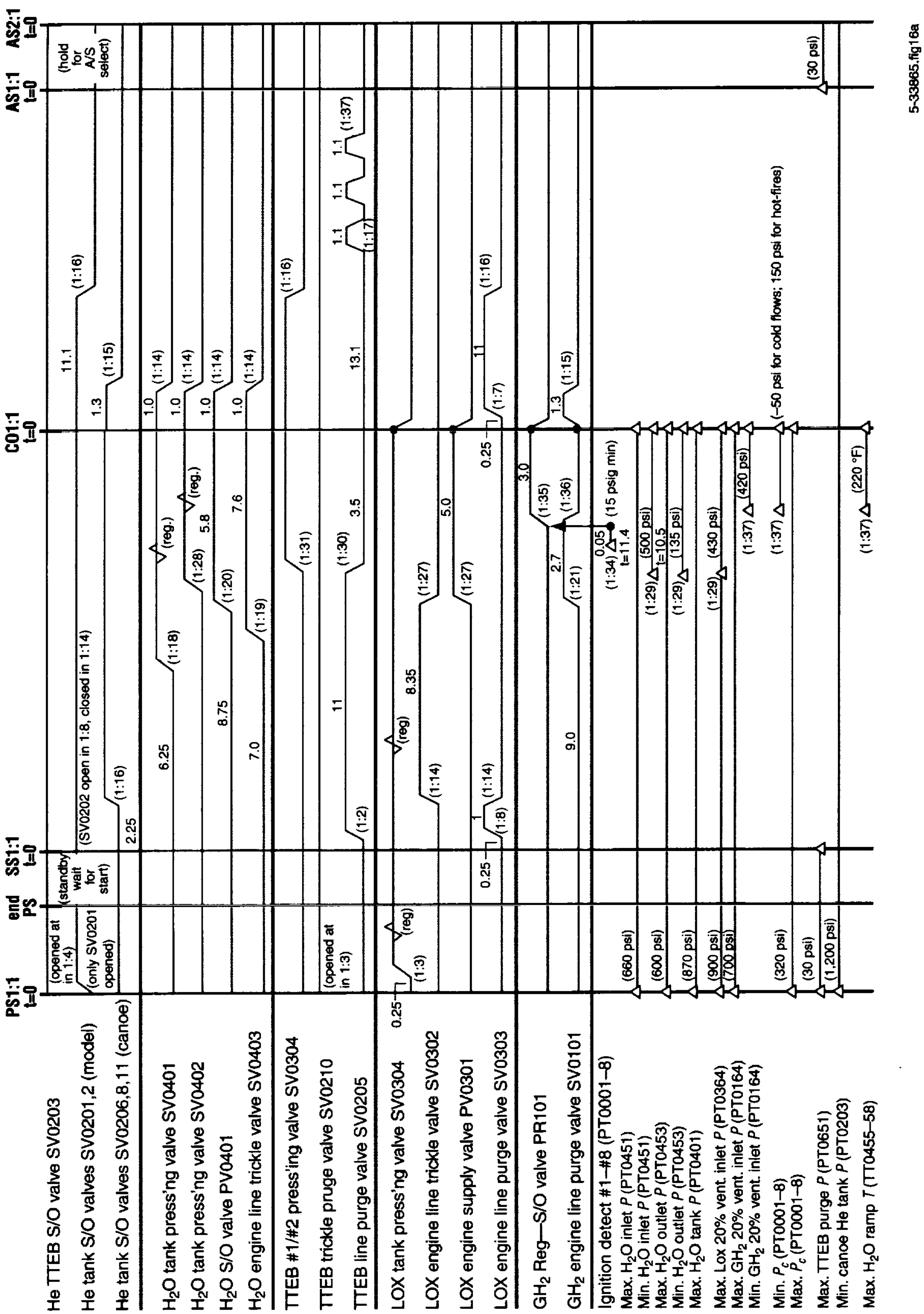


Figure 16. LASRE test sequence.

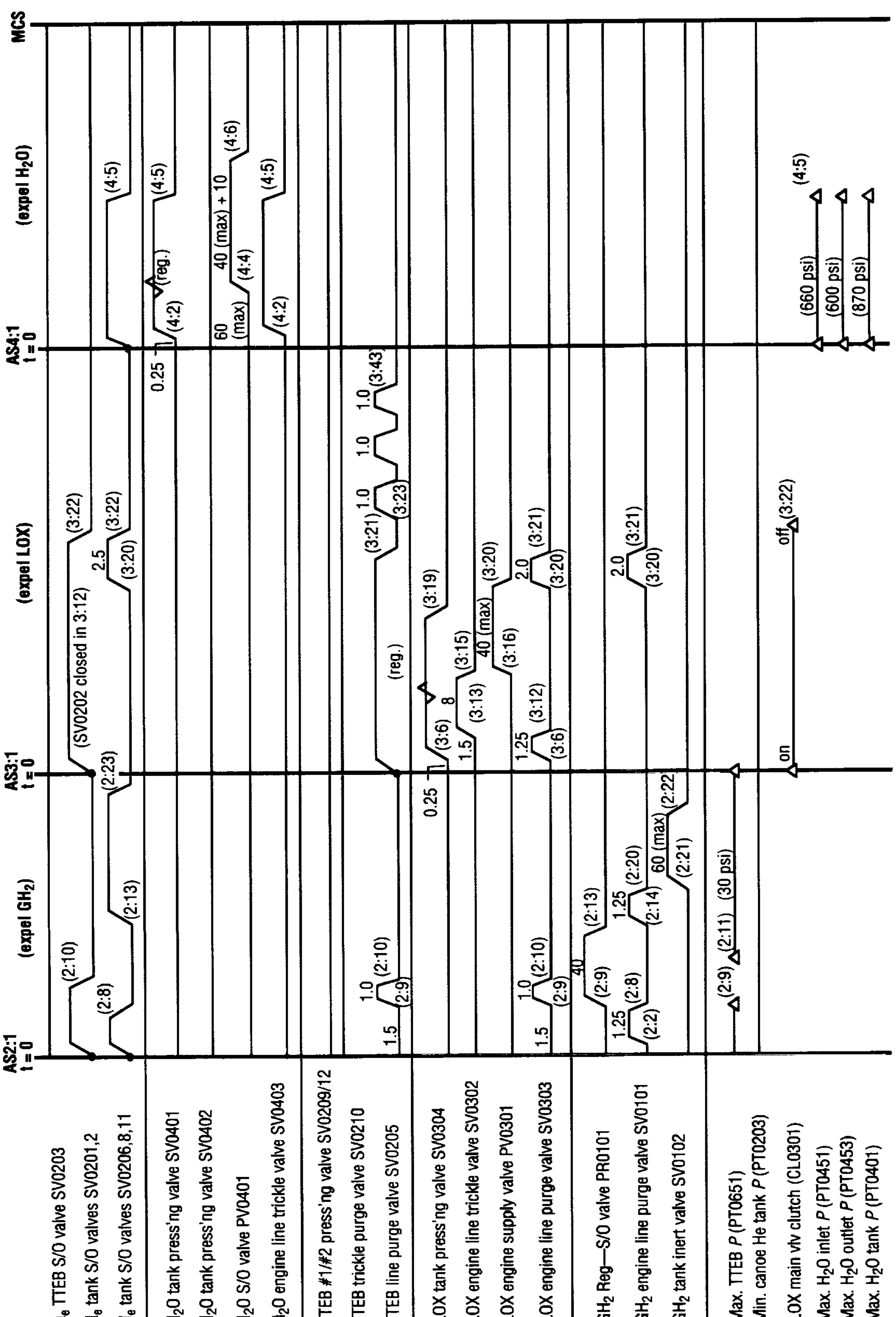


Figure 16. LASRE test sequence (Continued).

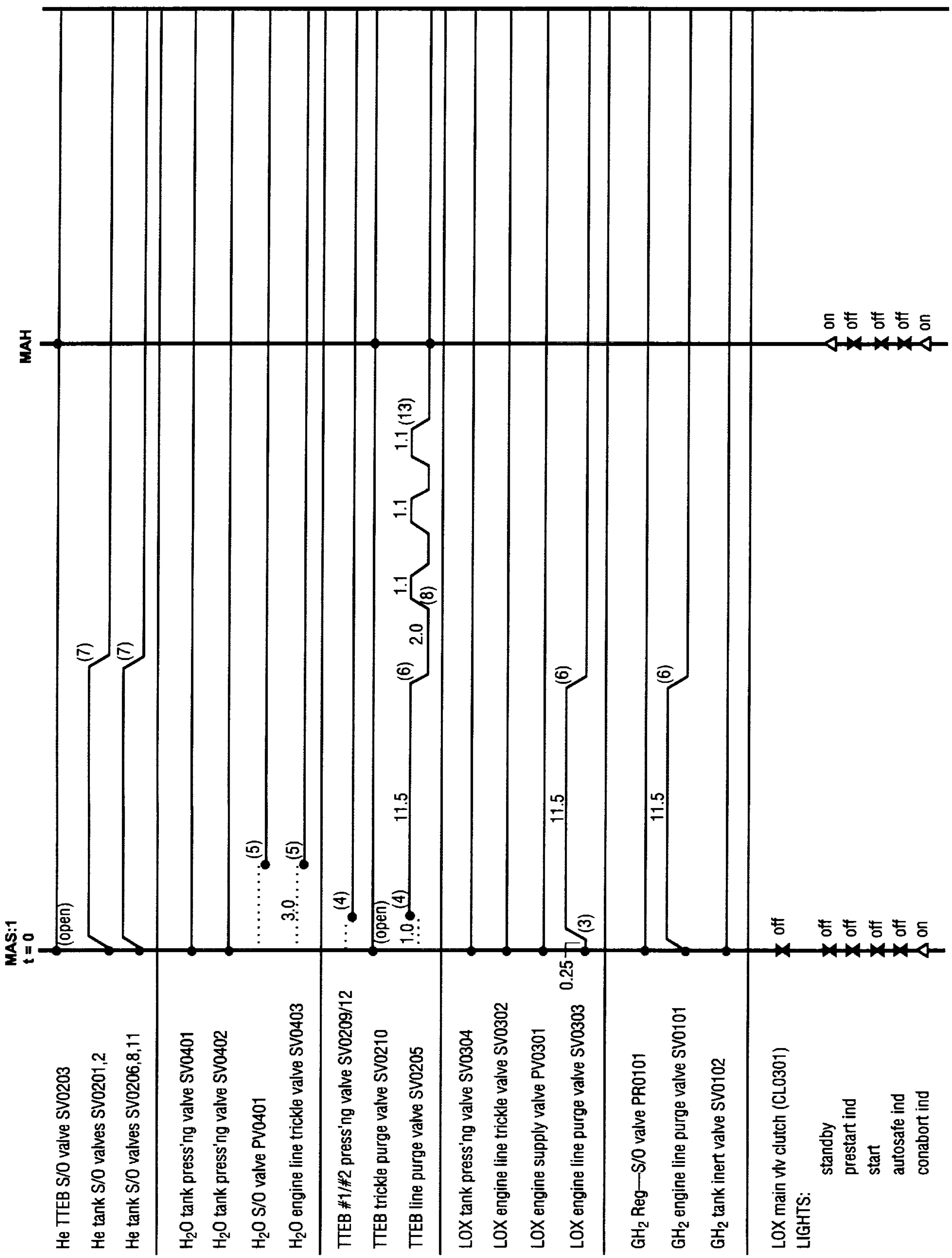


Figure 16. LASRE test sequence (Continued).

APPENDIX F—Summary of Steady-State Data

Note: Data from initial tests performed early in the program (GR'2–18) were not included in this summary. Also, the final flight configuration tests (GR'58–63 and FLT'51) were performed primarily to evaluate leaks in the LOX system; so, data from these tests were not included in the data summary sheets. Instead, their LOX system results were only included in the steady-state data plots (pp. 69–70, 75) to compare the LOX results with other tests.

A quick-look summary of LASRE system and engine and performance during main flow is shown in table 9, the system performance summary in table 10, and the engine performance summary in table 11.

Steady-state trends are shown for the LOX system data (fig. 17), fuel system data (fig. 18), water system data (fig. 19), and the thruster data (fig. 20). The LASRE engine supply systems are shown in figure 21, and figure 22 shows the thrusters and water system.

Additional test notes are shown in table 12.

Table 9. Quick-look summary of LASRE system and engine performance.

Test #	GRUN0057*		GRUN0056^	GRUN0055^		GRUN0054^		GRUN0052^	FLT0050*	FLT0049**
Test date	9/18/98		9/11/98	8/19/98		8/14/98		7/30/98	7/23/98	4/15/98
Test location	DFRC		DFRC	DFRC		DFRC		DFRC	DFRC	DFRC
Test Objective	Flt. cold flow		Flt. cold flow	Flt. cold flow		Flt. cold flow		Flt. cold flow	Flt. cold flow	Flt. cold flow
Blow #	1	2	2	1	2	1	2	1	1	1
Systems										
LOX System										
Fluid	LOX	LOX	LN2	LN2	LN2	LN2	LN2	LN2	LOX	LOX
ave tank P (psia)	368	366	369	366	374	365	361	358	360	360
ave. venturi inlet P (psia)	353	347	350	341	348	343	338	336	350	343
ave. venturi inlet T (F)	-278	-278	-300	-299	-300	-295	-296	-298	-277	-278
total LOX flow rate (lb$_m$/s)	11.8	11.6	11.4	11.2	11.4	11.0	11.0	11.1	11.7	11.7
Fuel System										
Fluid	GHe	GHe	GHe	GHe	GHe	GHe	GHe	GHe	GHe	GHe
supply P - d/s of valve (psia)	589	585	589	585	589	589	589	586	589	589
ave. venturi inlet P (psig)	483	478	482	479	478	482	478	475	480	482
ave. venturi inlet T (F)	69	47	66	67	46	75	51	53	64	52
total fuel flow rate (lb$_m$/s)	3.3	3.3	3.2	3.2	3.3	3.2	3.3	3.2	3.2	3.2
Water System										
Tank P (psia)	749	711	689	778	769	774	767	778	775	772
Engine Inlet P (psia)	578	551	534	600	594	599	597	608	603	603
Engine ΔP (psi)	383	358	346	397	392	389	387	399	399	404
Engine initial T (F)	72	73	69	74	74	77	76	84	85	62
Engine ΔT (F)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
est. flow rate (lb$_m$/s)	39.3	38.0	37.4	40.0	39.7	39.6	39.5	40.1	40.1	40.4
Engine										
HIGH Thrust Side (TH1-4)										
LOX flow rate, total (lb$_m$/s)	6.0	5.9	5.9	5.8	5.8	5.7	5.6	5.7	5.9	6.0
Fuel flow rate, total (lb$_m$/s)	1.62	1.63	1.62	1.62	1.64	1.62	1.64	1.62	1.57	1.61
ave. Pc (psig) [injector end]	30	31	31	29	29	31	29	30	32	30
ave. MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
ave. C*, efficiency	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
LOW Thrust Side (TH5-8)										
LOX flow rate, total (lb$_m$/s)	5.8	5.7	5.5	5.4	5.6	5.3	5.4	5.4	5.8	5.7
Fuel flow rate, total (lb$_m$/s)	1.63	1.64	1.63	1.61	1.64	1.62	1.64	1.62	1.59	1.61
ave. Pc (psig) [injector end]	31	30	29	28	29	30	28	29	31	31
ave. MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
ave. C*, efficiency	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Altitude (ft)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	31,000	26,000
Mach No.	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.9	0.75
Est. P_{atm} (psi)	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	4.0	4.0
reference t(0) [PDT]	9:02:55	9:13:10	9:09:45	7:50:20	7:58:15	8:28:20	8:36:25	7:13:50	8:34:55	10:10:32
data taken at Δt (sec)	19.6	19.2	18.6	19.5	17.6	16.2	20.4	17.1	16.6	19.3
Mainstage duration (sec)	3	3	3	3	3	3	3	3	3	3
reason for cutoff?	full duration	full duration	full duration	full duration	full duration	full duration	full duration	full duration	full duration	full duration

* GHe used in fuel/TTEB systems
** Ignition test - GHe used in fuel system
^ LN2/GHe used for LOX/GH2

Table 9. Quick-look summary of LASRE system and engine performance (Continued).

Test #	FLT0048^	FLT0047^	GRUN0046^		GRUN0041^	GRUN0038^	GRUN0037	GRUN0036	GRUN0035*
Test date	3/19/98	3/4/98	2/12/98		12/9/97	9/24/97	4/30/97	4/23/97	4/16/97
Test location	DFRC	DFRC	DFRC		DFRC	DFRC	Phillips Lab	Phillips Lab	Phillips Lab
Test Objective	Flt. cold flow	Flt. cold flow	Flt. cold flow		Flt. cold flow	Flt. cold flow	Gd. hot fire	Gd. hot fire	Gd. cold flow
Blow #	1	1	1	2	2	1	1	1	1
Systems									
LOX System									
Fluid	LN2	LN2	LN2	LN2	LN2	LN2	LOX	LOX	LOX
ave tank P (psia)	366	364	369	367	367	360	373	370	375
ave. venturi inlet P (psia)	342	347	345	352	348	340	346	349	353
ave. venturi inlet T (F)	-299	-299	-297	-297	-293	-302	-276	-279	-272
total LOX flow rate (lb_m/s)	11.3	11.3	11.1	11.3	10.9	11.3	11.5	11.7	11.5
Fuel System									
Fluid	GHe	GHe	GHe	GHe	GHe	GHe	GH2	GH2	GHe
supply P - d/s of valve (psia)	589	589	593	587	589	585	585	585	589
ave. venturi inlet P (psig)	484	481	484	479	475	479	466	468	459
ave. venturi inlet T (F)	65	57	62	64	75	52	40	31	69
total fuel flow rate (lb_m/s)	3.2	3.2	3.3	3.3	3.2	3.3	2.1	2.1	3.1
Water System									
Tank P (psia)	760	775	774	747	774	774	781	778	772
Engine Inlet P (psia)	596	599	606	584	603	613	601	601	597
Engine ΔP (psi)	400	400	400	388	390	359	398	402	402
Engine initial T (F)	67	68	56	57	55	77	63	60	68
Engine ΔT (F)	n/a	n/a	n/a	n/a	n/a	n/a	70	63	n/a
est. flow rate (lb_m/s)	40.2	40.2	40.2	39.6	39.7	38.0	40.1	40.2	40.3
Engine									
HIGH Thrust Side (TH1-4)									
LOX flow rate, total (lb_m/s)	5.8	5.8	5.7	5.8	5.6	5.8	5.9	6.0	5.9
Fuel flow rate, total (lb_m/s)	1.58	1.58	1.65	1.62	1.59	1.62	1.03	1.06	1.54
ave. Pc (psig) [injector end]	30	28	29	31	29	28	212	213	31
ave. MR	n/a	n/a	n/a	n/a	n/a	n/a	5.7	5.7	n/a
ave. C*, efficiency	n/a	n/a	n/a	n/a	n/a	n/a	96	94	n/a
LOW Thrust Side (TH5-8)									
LOX flow rate, total (lb_m/s)	5.5	5.5	5.4	5.5	5.3	5.5	5.6	5.7	5.6
Fuel flow rate, total (lb_m/s)	1.60	1.60	1.64	1.63	1.60	1.64	1.04	1.06	1.55
ave. Pc (psig) [injector end]	29	30	29	29	28	29	201	201	32
ave. MR	n/a	n/a	n/a	n/a	n/a	n/a	5.4	5.4	n/a
ave. C*, efficiency	n/a	n/a	n/a	n/a	n/a	n/a	94	92	n/a
Altitude (ft)	31,000	41,000	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Mach No.	0.9	1.2	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Est. P_{atm} (psi)	4.0	3.0	14.7	14.7	14.7	14.7	14.7	14.7	14.7
reference t(0) [PDT]	10:35:14	10:54:15	9:12:55	9:20:55	9:54:05	8:15:50	12:50:45	13:18:47	14:49:20
data taken at Δt (sec)	19.3	19.2	16.6	17.6	15.0	18.0	18.7	6.1	23.8
Mainstage duration (sec)	3	3	3	1	1	3	3	3	3
reason for cutoff?	full duration	full duration	full duration	Abort with CNTR PWR OFF as planned	Abort with EMERSS as planned	full duration	full duration	full duration	full duration

* GHe used in fuel/TTEB systems
** Ignition test - GHe used in fuel system
^ LN2/GHe used for LOX/GH2

Table 9. Quick-look summary of LASRE system and engine performance (Continued).

Test #	GRUN0057*		GRUN0056^	GRUN0055^		GRUN0054^		GRUN0052^	FLT0050*	FLT0049**
Test date	9/18/98		9/11/98	8/19/98		8/14/98		7/30/98	7/23/98	4/15/98
Test location	DFRC		DFRC	DFRC		DFRC		DFRC	DFRC	DFRC
Test Objective	Flt. cold flow		Flt. cold flow	Flt. cold flow		Flt. cold flow		Flt. cold flow	Flt. cold flow	Flt. cold flow
Blow #	1	2	2	1	2	1	2	1	1	1
Systems										
LOX System										
Fluid	LOX	LOX	LN2	LN2	LN2	LN2	LN2	LN2	LOX	LOX
ave tank P (psia)	368	366	369	366	374	365	361	358	360	360
ave. venturi inlet P (psia)	353	347	350	341	348	343	338	336	350	343
ave. venturi inlet T (F)	-278	-278	-300	-299	-300	-295	-296	-298	-277	-278
total LOX flow rate (lb_m/s)	11.8	11.6	11.4	11.2	11.4	11.0	11.0	11.1	11.7	11.7
Fuel System										
Fluid	GHe	GHe	GHe	GHe	GHe	GHe	GHe	GHe	GHe	GHe
supply P - d/s of valve (psia)	589	585	589	585	589	589	589	586	589	589
ave. venturi inlet P (psig)	483	478	482	479	478	482	478	475	480	482
ave. venturi inlet T (F)	69	47	66	67	46	75	51	53	64	52
total fuel flow rate (lb_m/s)	3.3	3.3	3.2	3.2	3.3	3.2	3.3	3.2	3.2	3.2
Water System										
Tank P (psia)	749	711	689	778	769	774	767	778	775	772
Engine Inlet P (psia)	578	551	534	600	594	599	597	608	603	603
Engine ΔP (psi)	383	358	346	397	392	389	387	399	399	404
Engine initial T (F)	72	73	69	74	74	77	76	84	85	62
Engine ΔT (F)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
est. flow rate (lb_m/s)	39.3	38.0	37.4	40.0	39.7	39.6	39.5	40.1	40.1	40.4
Engine										
HIGH Thrust Side (TH1-4)										
LOX flow rate, total (lb_m/s)	6.0	5.9	5.9	5.8	5.8	5.7	5.6	5.7	5.9	6.0
Fuel flow rate, total (lb_m/s)	1.62	1.63	1.62	1.62	1.64	1.62	1.64	1.62	1.57	1.61
ave. Pc (psig) [injector end]	30	31	31	29	29	31	29	30	32	30
ave. MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
ave. C*, efficiency	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
LOW Thrust Side (TH5-8)										
LOX flow rate, total (lb_m/s)	5.8	5.7	5.5	5.4	5.6	5.3	5.4	5.4	5.8	5.7
Fuel flow rate, total (lb_m/s)	1.63	1.64	1.63	1.61	1.64	1.62	1.64	1.62	1.59	1.61
ave. Pc (psig) [injector end]	31	30	29	28	29	30	28	29	31	31
ave. MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
ave. C*, efficiency	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Altitude (ft)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	31,000	26,000
Mach No.	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.9	0.75
Est. P_{atm} (psi)	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	4.0	4.0
reference t(0) [PDT]	9:02:55	9:13:10	9:09:45	7:50:20	7:58:15	8:28:20	8:36:25	7:13:50	8:34:55	10:10:32
data taken at Δt (sec)	19.6	19.2	18.6	19.5	17.6	16.2	20.4	17.1	16.6	19.3
Mainstage duration (sec)	3	3	3	3	3	3	3	3	3	3
reason for cutoff?	full duration	full duration	full duration	full duration	full duration	full duration	full duration	full duration	full duration	full duration

* GHe used in fuel/TTEB systems

** Ignition test - GHe used in fuel system

^ LN2/GHe used for LOX/GH2

Table 9. Quick-look summary of LASRE system and engine performance (Continued).

Test #	GRUN0027*		GRUN0026*		GRUN0025*		GRUN0024*		GRUN0023*		GRUN0022*	
Test date	12/3/96		11/22/96		11/15/96		11/1/96		10/25/96		10/12/96	
Test location	Phillips Lab		Phillips Lab		Phillips Lab		Phillips Lab		Phillips Lab		Phillips Lab	
Test Objective	Gd. cold flow		Gd. cold flow		Gd. cold flow		Gd. cold flow		Gd. cold flow		Gd. cold flow	
Blow #	1	2	1	2	1	2	1	"2"	1	2	1	2
Systems												
LOX System												
Fluid	LOX	LOX	LOX	LOX	LOX	LOX	LOX	LOX	LOX	LOX	LOX	LOX
ave tank P (psia)	367	366	375	369	369	376	371	372	373	373	369	368
ave. venturi inlet P (psia)	348	341	352	355	353	355	349	351	349	349	341	352
ave. venturi inlet T (F)	-269	-266	-270	-268	-269	-271	-266	-254	-269	-270	-263	-261
total LOX flow rate (lb_m/s)	11.1	10.7	11.3	11.2	11.2	11.4	10.8	10.1	11.2	11.2	10.7	10.6
Fuel System												
Fluid	GHe	GHe	GHe	GHe	GHe	GHe	GHe	GHe	GHe	GHe	GHe	GHe
supply P - d/s of valve (psia)	593	16	593	591	592	589	593	589	566	578	593	589
ave. venturi inlet P (psig)	451	-3	453	451	457	456	458	455	437	453	468	466
ave. venturi inlet T (F)	74	58	82	49	73	67	88	78	68	52	91	78
total fuel flow rate (lb_m/s)	3.0	n/a	3.0	3.1	3.1	3.1	3.0	3.0	2.9	3.1	3.1	3.1
Water System												
Tank P (psia)	781	781	777	771	779	777	769	777	780	777	773	772
Engine Inlet P (psia)	624	677	619	626	617	643	605	610	607	602	606	602
Engine ΔP (psi)	446	581	439	459	435	486	407	422	412	411	411	406
Engine initial T (F)	45	44	56	54	54	52	61	63	59	57	78	77
Engine ΔT (F)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
est. flow rate (lb_m/s)	36.1	26.5	35.2	33.7	35.6	32.4	40.5	36.2	40.8	40.7	40.7	40.5
Engine												
HIGH Thrust Side (TH1-4)												
LOX flow rate, total (lb_m/s)	5.5	5.4	5.7	5.7	5.6	5.7	5.4	5.0	5.6	5.6	5.4	5.2
Fuel flow rate, total (lb_m/s)	1.53	n/a	1.52	1.57	1.54	1.54	1.52	1.51	1.48	1.54	1.51	1.51
ave. Pc (psig) [injector end]	30	2	31	31	31	30	31	30	29	31	31	31
ave. MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
ave. C*, efficiency	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
LOW Thrust Side (TH5-8)												
LOX flow rate, total (lb_m/s)	5.6	5.3	5.6	5.5	5.6	5.7	5.4	5.1	5.6	5.6	5.3	5.4
Fuel flow rate, total (lb_m/s)	1.50	n/a	1.48	1.53	1.51	1.52	1.50	1.51	1.46	1.55	1.58	1.59
ave. Pc (psig) [injector end]	31	1	31	30	29	29	32	32	30	31	31	31
ave. MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
ave. C*, efficiency	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Altitude (ft)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Mach No.	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Est. P_{atm} (psi)	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7
reference t(0) [PDT]	13:15:44	13:23:00	13:51:25	14:00:04	13:39:55	13:46:05	12:38:50	14:01:40	13:54:50	14:01:30	14:32:00	14:38:20
data taken at Δt (sec)	36.0	41.8	41.0	41.0	40.0	39.3	40.0	40.0	43.0	41.0	45.5	47.0
Mainstage duration (sec)	3	0	3	3	3	~0.8	3	3	3	3	3	3
reason for cutoff?	full duration	PT0401 R/L (frozen water)	full duration	full duration	full duration	PT0164 R/L (when burst disc failed)	full duration	full duration	full duration	full duration	full duration	full duration

* GHe used in fuel/TTEB systems

** Ignition test - GHe used in fuel system

^ LN2/GHe used for LOX/GH2

Table 9. Quick-look summary of LASRE system and engine performance (Continued).

Test #	GRUN0020*		GRUN0019*	
Test date	9/1/96		7/26/96	
Test location	Phillips Lab		Phillips Lab	
Test Objective	Gd. cold flow		Gd. cold flow	
Blow #	1	2	1	2
Systems				
LOX System				
Fluid	LOX	LOX	LOX	LOX
ave tank P (psia)	363	---	363	370
ave. venturi inlet P (psia)	345	---	347	336
ave. venturi inlet T (F)	-267	---	-276	-273
total LOX flow rate (lb_m/s)	11.1	---	11.5	11.3
Fuel System				
Fluid	GHe	GHe	GHe	GHe
supply P - d/s of valve (psia)	320	---	581	577
ave. venturi inlet P (psig)	250	---	456	458
ave. venturi inlet T (F)	110	---	98	82
total fuel flow rate (lb_m/s)	1.7	---	3.0	3.1
Water System				
Tank P (psia)	781	---	774	766
Engine Inlet P (psia)	579	---	574	556
Engine ΔP (psi)	389	---	377	377
Engine initial T (F)	87	---	91	92
Engine ΔT (F)	n/a	---	n/a	n/a
est. flow rate (lb_m/s)	39.6	---	39.6	39.6
Engine				
HIGH Thrust Side (TH1-4)				
LOX flow rate, total (lb_m/s)	5.6	---	5.8	5.6
Fuel flow rate, total (lb_m/s)	0.82	---	1.49	1.52
ave. Pc (psig) [injector end]	18	---	32	31
ave. MR	n/a	---	n/a	n/a
ave. C*, efficiency	n/a	---	n/a	n/a
LOW Thrust Side (TH5-8)				
LOX flow rate, total (lb_m/s)	5.5	---	5.7	5.7
Fuel flow rate, total (lb_m/s)	0.86	---	1.52	1.53
ave. Pc (psig) [injector end]	14	---	32	30
ave. MR	n/a	---	n/a	n/a
ave. C*, efficiency	n/a	---	n/a	n/a
Altitude (ft)	n/a	n/a	n/a	n/a
Mach No.	n/a	n/a	n/a	n/a
Est. P_{atm} (psi)	14.7	14.7	14.7	14.7
reference t(0) [PDT]	13:55:15	14:05:00	14:22:45	14:26:55
data taken at Δt (sec)	38.0	---	45.0	38.0
Mainstage duration (sec)	3	0	3	3
reason for cutoff?	full duration	PS1:17 limit on LOX ΔT	full duration	full duration

* GHe used in fuel/TTEB systems
** Ignition test - GHe used in fuel system
^ LN2/GHe used for LOX/GH2

Table 10. Summary of LASRE system performance.

Test #	GRUN0057*		GRUN0056^	GRUN0055^		GRUN0054^		GRUN0052^	FLT0050*	FLT0049**
Test date	9/18/98		9/11/98	8/19/98		8/14/98		7/30/98	7/23/98	4/15/98
Test Objective	Flt. cold flow		Flt. cold flow	Flt. cold flow		Flt. cold flow		Flt. cold flow	Flt. cold flow	Flt. cold flow
Blow #	1	2	2	1	2	1	2	1	1	1
LOX System										
ave. tank P (psia) [PT0302 & PT0301]	368	366	369	366	374	365	361	358	360	360
100% venturi inlet P (psia) [PT0360]	354	347	351	342	343	341	341	335	341	347
100% venturi inlet T_2(F) [TT0360]	-281	-280	-305	-302	-304	-299	-297	-300	-280	-282
100% venturi ACd (in)	0.0609	0.0609	0.0609	0.0609	0.0609	0.0609	0.0609	0.0609	0.0609	0.0609
100% venturi flow rate (lb_m/s)	6.0	5.9	5.9	5.8	5.8	5.7	5.6	5.7	5.9	6.0
80% venturi inlet P (psia) [PT0363]	351	346	349	342	349	346	336	334	364	341
80% venturi inlet T (F) [TT0363]	-279	-278	-298	-300	-299	-295	-299	-301	-278	-278
80%venturi throat P (psia) [PT0362]	37	32	35	33	27	45	39	34	36	40
80% venturi ACd (in^2)	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473
80% venturi flow rate (lb_m/s)	4.7	4.6	4.4	4.4	4.5	4.3	4.4	4.4	4.7	4.6
20% venturi inlet P (psia) [PT0364]	353	349	350	339	354	341	337	340	345	340
20% venturi inlet T (F) [TT0364]	-276	-276	-297	-295	-298	-290	-293	-293	-274	-274
20% venturi throat P_2 (psia) [PT0361]	48	48	49	51	54	59	58	52	54	50
20% venturi ACd (in)	0.01154	0.01154	0.01154	0.01154	0.01154	0.01154	0.01154	0.01154	0.01154	0.01154
20% venturi flow rate (lb_m/s)	1.1	1.1	1.1	1.0	1.1	1.0	1.0	1.0	1.1	1.1
LOX flow rate (lb_m/s), high thrust side	6.0	5.9	5.9	5.8	5.8	5.7	5.6	5.7	5.9	6.0
LOX flow rate (lb_m/s), low thrust side	5.8	5.7	5.5	5.4	5.6	5.3	5.4	5.4	5.8	5.7
Fuel System										
Tanks (psia) [PT0101]	4209	3043	4283	4203	3044	4107	2884	2687	2840	3671
Supply d/s of valve (psia) [PT0102]	589	585	589	585	589	589	589	586	589	589
100% venturi inlet P (psig) [PT0160]	481	474	480	480	477	483	477	474	475	479
100% venturi inlet T (F) [TT0160]	65	45	64	64	43	73	49	52	62	50
100% venturi ACd (in^2)	0.3575	0.3575	0.3575	0.3575	0.3575	0.3575	0.3575	0.3575	0.3575	0.3575
100% venturi flow rate (lb_m/s)	1.62	1.63	1.62	1.62	1.64	1.62	1.64	1.62	1.57	1.61
80% venturi inlet P (psig) [PT0163]	487	479	484	482	480	486	481	477	478	479
80% venturi inlet T (F) [TT0163]	71	49	68	69	49	75	54	54	64	52
80% venturi ACd (in^2)	0.2816	0.2816	0.2816	0.2816	0.2816	0.2816	0.2816	0.2816	0.2816	0.2816
80% venturi flow rate (lb_m/s)	1.29	1.29	1.28	1.28	1.30	1.28	1.29	1.28	1.25	1.26
20% venturi inlet P (psig) [PT0164]	481	481	482	473	476	477	475	474	486	489
20% venturi inlet T (F) [TT0164]	70	46	65	67	46	77	50	54	65	55
20% venturi ACd (in^2)	0.07559	0.07559	0.07559	0.07559	0.07559	0.07559	0.07559	0.07559	0.07559	0.07559
20% venturi flow rate (lb_m/s)	0.34	0.35	0.34	0.34	0.35	0.34	0.34	0.34	0.34	0.34
Fuel flow rate (lb_m/s), high thrust side	1.62	1.63	1.62	1.62	1.64	1.62	1.64	1.62	1.57	1.61
Fuel flow rate (lb_m/s), low thrust side	1.63	1.64	1.62	1.62	1.65	1.62	1.63	1.62	1.59	1.61
TTEB System										
Supply P to engine (psia) [PT0651]	599	611	615	603	610	606	612	608	595	581
TTEB density (lb_m/ft^3)	GHe purge	GHe purge	GHe purge	GHe purge	GHe purge	GHe purge	GHe purge	GHe purge	GHe purge	GHe purge
Orifice to each thruster (in)	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
flow rate to each thruster (lb_m/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Water System										
Tank P (psia) [PT0401]	749	711	689	778	769	774	767	778	775	772
Engine inlet P (psia) [PT0451]	578	551	534	600	594	599	597	608	603	603
Engine exit P (psia) [PT0453]	195	193	187	203	202	210	210	210	204	199
Engine ΔP (psi)	383	358	346	397	392	389	387	399	399	404
Engine inlet T (F) [TT0451]	72	73	69	74	74	77	76	84	85	62
Engine exit T (F) [TT0453]	66	64	62	67	66	71	70	76	76	49
min. initial engine exit T (F) [TT0453]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Engine ΔT (F) relative to TT0453	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
High Thrust Side Ramp										
Upper T (F) [TT0455]	70	70	68	72	72	76	74	83	83	48
Lower T (F) [TT0456]	70	70	68	72	71	75	75	82	81	54
Low Thrust Side Ramp										
Upper T (F) [TT0457]	72	72	68	72	71	77	76	83	84	55
Lower T (F) [TT0458]	71	70	68	72	72	76	75	83	82	55
Total water flow rate (lb_m/s)***	39.3	38.0	37.4	40.0	39.7	39.6	39.5	40.1	40.1	40.4

* GHe used in fuel/TTEB systems ** Ignition test- GHe used in fuel system *** est. w/engine ΔP when F/M inop ^ LN2/GHe used for LOX/GH2

Table 10. Summary of LASRE system performance (Continued).

Test #	FLT0048^	FLT0047^	GRUN0046^		GRUN0041^	GRUN0038^	GRUN0037	GRUN0036	GRUN0035*
Test date	3/19/98	3/4/98	2/12/98		12/9/97	9/24/97	4/30/97	4/23/97	4/16/97
Test Objective	Flt. cold flow	Flt. cold flow	Flt. cold flow		Flt. cold flow	Flt. cold flow	Gd. hot fire	Gd. hot fire	Gd. cold flow
Blow #	1	1	1	2	2	1	1	1	1
LOX System									
ave. tank P (psia) [PT0302 & PT0301]	366	364	369	367	367	360	373	370	375
100% venturi inlet P (psia) [PT0360]	344	349	346	352	349	338	351	352	361
100% venturi inlet T (F) [TT0360]	-301	-304	-300	-300	-296	-304	-276	-281	-273
100% venturi ACd (in^2)	0.0609	0.0609	0.0609	0.0609	0.0609	0.0609	0.0609	0.0609	0.0609
100% venturi flow rate (lb_m/s)	5.8	5.8	5.7	5.8	5.6	5.8	5.9	6.0	5.9
80% venturi inlet P (psia) [PT0363]	341	348	342	348	345	337	341	347	350
80% venturi inlet T (F) [TT0363]	-300	-298	-298	-299	-294	-302	-277	-280	-273
80% venturi throat P (psia) [PT0362]	39	39	34	39	44	n/a	28	31	38
80% venturi ACd (in^2)	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473
80% venturi flow rate (lb_m/s)	4.4	4.4	4.4	4.5	4.3	4.4	4.5	4.60	4.5
20% venturi inlet P (psia) [PT0364]	342	344	346	356	350	344	346	350	349
20% venturi inlet T (F) [TT0364]	-295	-296	-295	-293	-290	-299	-274	-277	-269
20% venturi throat P (psia) [PT0361]	51	50	49	54	57	51	74	84	51
20% venturi ACd (in^2)	0.01154	0.01154	0.01154	0.01154	0.01154	0.01154	0.01154	0.01154	0.01154
20% venturi flow rate (lb_m/s)	1.1	1.1	1.0	1.0	1.0	1.1	1.1	1.1	1.1
LOX flow rate (lb_m/s), high thrust side	5.8	5.8	5.7	5.8	5.6	5.8	5.9	6.0	5.9
LOX flow rate (lb_m/s), low thrust side	5.5	5.5	5.4	5.5	5.3	5.5	5.6	5.7	5.6
Fuel System									
Tanks (psia) [PT0101]	4205	3947	4326	4058	5123	2539	2325	2308	2712
Supply d/s of valve (psia) [PT0102]	589	589	593	587	589	585	585	585	589
100% venturi inlet P (psig) [PT0160]	479	475	487	478	475	474	466	469	457
100% venturi inlet T (F) [TT0160]	64	55	60	62	73	51	39	29	67
100% venturi ACd (in^2)	0.3575	0.3575	0.3575	0.3575	0.3575	0.3575	0.3575	0.3575	0.3575
100% venturi flow rate (lb_m/s)	1.58	1.58	1.65	1.62	1.59	1.62	1.03	1.06	1.54
80% venturi inlet P (psig) [PT0163]	486	479	487	484	480	480	467	470	461
80% venturi inlet T (F) [TT0163]	65	57	61	64	76	53	41	32	69
80% venturi ACd (in^2)	0.2816	0.2816	0.2816	0.2816	0.2816	0.2816	0.2816	0.2816	0.2816
80% venturi flow rate (lb_m/s)	1.26	1.25	1.30	1.29	1.26	1.29	0.82	0.84	1.22
20% venturi inlet P (psig) [PT0164]	487	489	477	476	471	483	466	465	458
20% venturi inlet T (F) [TT0164]	67	59	63	65	77	53	42	32	70
20% venturi ACd (in^2)	0.07559	0.07559	0.07559	0.07559	0.07559	0.07559	0.07559	0.07559	0.07559
20% venturi flow rate (lb_m/s)	0.34	0.34	0.34	0.34	0.33	0.35	0.22	0.22	0.33
Fuel flow rate (lb_m/s), high thrust side	1.58	1.58	1.65	1.62	1.59	1.62	1.03	1.06	1.54
Fuel flow rate (lb_m/s), low thrust side	1.60	1.60	1.64	1.63	1.60	1.64	1.04	1.06	1.55
TTEB System									
Supply P to engine (psia) [PT0651]	588	586	591	621	616	609	604	610	588
TTEB density (lb_m/ft3)	GHe purge	GHe purge	GHe purge	GHe purge	GHe purge	GHe purge	GHe purge	GHe purge	GHe purge
Orifice to each thruster (in)	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
flow rate to each thruster (lb_m/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Water System									
Tank P (psia) [PT0401]	760	775	774	747	774	774	781	778	772
Engine inlet P (psia) [PT0451]	596	599	606	584	603	613	601	601	597
Engine exit P (psia) [PT0453]	196	199	206	196	212	254	203	199	195
Engine ΔP (psi)	400	400	400	388	390	359	398	402	402
Engine inlet T (F) [TT0451]	67	68	56	57	55	77	64	65	68
Engine exit T (F) [TT0453]	59	59	51	49	48	69	133	123	64
min. initial engine exit T (F) [TT0453]	n/a	n/a	n/a	n/a	n/a	n/a	63	60	n/a
Engine ΔT (F) relative to TT0453	n/a	n/a	n/a	n/a	n/a	n/a	70	63	n/a
High Thrust Side Ramp									
Upper T (F) [TT0455]	57	58	47	47	45	66	147	144	69
Lower T (F) [TT0456]	64	65	54	53	51	73	147	145	70
Low Thrust Side Ramp									
Upper T (F) [TT0457]	69	68	60	59	54	75	148	144	71
Lower T (F) [TT0458]	65	64	55	55	54	74	140	136	70
Total water flow rate (lb_m/s)***	40.2	40.2	40.2	39.6	39.7	38.0	40.1	40.2	40.3

* GHe used in fuel/TTEB systems ** Ignition test - GHe used in fuel system *** est. w/engine ΔP when F/M inop ^ LN2/GHe used for LOX/GH2

Table 10. Summary of LASRE system performance (Continued).

Test #	GRUN0033**				GRUN0032**		GRUN0031**		GRUN0030*	GRUN0029*	GRUN0028*
Test date	2/6/97				1/31/97		1/23/97		1/18/97	12/17/96	12/11/96
Test Objective	Ignition test				Ignition test		Ignition test		Gd. cold flow	Gd. cold flow	Gd. cold flow
Blow #	1-ign	1-main	2-ign	2-main	1-ign	1-main	1-ign	1-main	1	2	1
LOX System											
ave. tank P (psia) [PT0302 & PT0301]	377	369	369	369	370	362	365	372	369	372	360
100% venturi inlet P (psia) [PT0360]	354	351	352	354	368	361	354	355	349	348	350
100% venturi inlet T (F) [TT0360]	-273	-279	-270	-274	-246	-252	-274	-281	-278	-279	-282
100% venturi ACd (in²)	0.0609	0.0609	0.0609	0.0609	0.0609	0.0609	0.0609	0.0609	0.0609	0.0609	0.0609
100% venturi flow rate (lb_m/s)	5.8	5.9	5.7	5.8	3.0	4.0	5.8	5.9	5.9	5.9	6.0
80% venturi inlet P (psia) [PT0363]	357	352	343	343	355	347	345	351	344	340	344
80% venturi inlet T (F) [TT0363]	-273	-276	-270	-273	-248	-253	-272	-279	-276	-277	-280
80% venturi throat P (psia) [PT0362]	41	36	45	34	262	216	49	35	25	27	36
80% venturi ACd (in²)	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473
80% venturi flow rate (lb_m/s)	4.6	4.6	4.4	4.5	2.4	2.9	4.5	4.6	4.6	4.5	4.6
20% venturi inlet P (psia) [PT0364]	355	355	344	347	359	354	346	349	352	346	348
20% venturi inlet T (F) [TT0364]	-266	-279	-262	-272	-239	-239	-266	-279	-277	-276	-278
20% venturi throat P (psia) [PT0361]	76	50	66	51	238	195	67	48	47	44	51
20% venturi ACd (in²)	0.01154	0.01154	0.01154	0.01154	0.01154	0.01154	0.01154	0.01154	0.01154	0.01154	0.01154
20% venturi flow rate (lb_m/s)	1.1	1.1	1.0	1.1	0.7	0.8	1.0	1.1	1.1	1.1	1.1
LOX flow rate (lb_m/s), high thrust side	5.8	5.9	5.7	5.8	3.0	4.0	5.8	5.9	5.9	5.9	6.0
LOX flow rate (lb_m/s), low thrust side	5.7	5.7	5.4	5.6	3.1	3.65	5.5	5.7	5.7	5.6	5.7
Fuel System											
Tanks (psia) [PT0101]	6147	5048	5305	4329	6099	4788	6050	4465	3669	4595	4739
Supply d/s of valve (psia) [PT0102]	GHe purge	593	GHe purge	593	GHe purge	589	GHe purge	589	589	593	593
100% venturi inlet P (psig) [PT0160]	30	462	37	460	13	459	34	460	463	458	467
100% venturi inlet T (F) [TT0160]	65	66	55	56	70	75	58	58	47	54	68
100% venturi ACd (in²)	0.3575	0.3575	0.3575	0.3575	0.3575	0.3575	0.3575	0.3575	0.3575	0.3575	0.3575
100% venturi flow rate (lb_m/s)	n/a	1.56	n/a	1.57	n/a	1.54	n/a	1.57	1.59	1.57	1.57
80% venturi inlet P (psig) [PT0163]	34	471	32	469	13	468	34	464	470	467	464
80% venturi inlet T (F) [TT0163]	57	68	55	58	72	77	58	60	49	56	69
80% venturi ACd (in²)	0.2816	0.2816	0.2816	0.2816	0.2816	0.2816	0.2816	0.2816	0.2816	0.2816	0.2816
80% venturi flow rate (lb_m/s)	n/a	1.25	n/a	1.26	n/a	1.23	n/a	1.24	1.27	1.25	1.23
20% venturi inlet P (psig) [PT0164]	34	466	42	462	17	464	34	465	456	459	452
20% venturi inlet T (F) [TT0164]	57	68	56	61	73	79	59	61	50	59	70
20% venturi ACd (in²)	0.07559	0.07559	0.07559	0.07559	0.07559	0.07559	0.07559	0.07559	0.07559	0.07559	0.07559
20% venturi flow rate (lbm/s)	n/a	0.33	n/a	0.33	n/a	0.33	n/a	0.33	0.33	0.33	0.32
Fuel flow rate (lb_m/s), high thrust side	n/a	1.56	n/a	1.57	n/a	1.54	n/a	1.57	1.59	1.57	1.57
Fuel flow rate (lb_m/s), low thrust side	n/a	1.58	n/a	1.59	n/a	1.56	n/a	1.58	1.60	1.58	1.55
TTEB System											
Supply P to engine (psia) [PT0651]	693	606	704	595	709	624	690	597	599	599	590
TTEB density (lb_m/ft^3)	44.5	GHe purge	44.5	GHe purge	44.5	GHe purge	44.5	GHe purge	n/a	n/a	n/a
Orifice to each thruster (in)	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
flow rate to each thruster (lb_m/s)	0.036	n/a	0.036	n/a	0.037	n/a	0.036	n/a	n/a	n/a	n/a
Water System											
Tank P (psia) [PT0401]	772	780	742	779	775	779	777	775	780	778	780
Engine inlet P (psia) [PT0451]	585	588	570	598	593	598	598	589	593	600	606
Engine exit P (psia) [PT0453]	193	200	178	188	199	198	198	190	203	202	197
Engine ΔP (psi)	392	388	392	410	394	400	400	399	390	398	409
Engine inlet T (F) [TT0451]	45	46	48	47	56	57	52	51	47	48	53
Engine exit T (F) [TT0453]	44	41	43	42	56	55	48	47	43	41	46
min. initial engine exit T (F) [TT0453]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Engine ΔT (F) relative to TT0453	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
High Thrust Side Ramp											
Upper T (F) [TT0455]	48	48	48	48	61	61	52	52	48	49	52
Lower T (F) [TT0456]	45	46	46	46	59	60	51	51	47	47	51
Low Thrust Side Ramp											
Upper T (F) [TT0457]	48	48	48	46	62	61	53	52	49	49	53
Lower T (F) [TT0458]	48	47	47	46	60	60	53	53	49	47	54
Total water flow rate (lb_m/s)***	39.8	39.5	39.8	40.7	39.9	40.2	40.2	40.1	39.7	40.1	40.6

* GHe used in fuel/TTEB systems ** Ignition test - GHe used in fuel system *** est. w/engine ΔP when F/M inop ^ LN2/GHe used for LOX/GH2

Table 10. Summary of LASRE system performance (Continued).

Test #	GRUN0027*		GRUN0026*		GRUN0025*		GRUN0024*		GRUN0023*		GRUN0022*	
Test date	12/3/96		11/22/96		11/15/96		11/9/96		10/25/96		10/12/96	
Test Objective	Gd. cold flow		Gd. cold flow		Gd. cold flow		Gd. cold flow		Gd. cold flow		Gd. cold flow	
Blow #	1	2	1	2	1	2	1	'2'	1	2	1	2
LOX System												
ave. tank P (psia) [PT0302 & PT0301]	367	366	375	369	369	376	371	372	373	373	369	368
100% venturi inlet P (psia) [PT0360]	345	341	360	362	356	357	349	353	352	351	assume 350	
100% venturi inlet T (F) [TT0360]	-267	-264	-267	-266	-267	-268	-262	-251	-266	-267	-261	-257
100% venturi ACd (in^2)	0.0609	0.0609	0.0609	0.0609	0.0609	0.0609	0.0609	0.0609	0.0609	0.0609	0.0609	0.0609
100% venturi flow rate (lb$_m$/s)	5.5	5.4	5.7	5.7	5.6	5.7	5.4	5.0	5.6	5.6	5.4	5.2
80% venturi inlet P (psia) [PT0363]	349	337	347	348	352	354	351	348	345	346	347	352
80% venturi inlet T (F) [TT0363]	-271	-268	-273	-270	-270	-274	-268	-257	-273	-273	-266	-266
80% venturi throat P (psia) [PT0362]	26	31	33	29	29	34	27	52	33	29	48	46
80% venturi ACd (in^2)	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473
80% venturi flow rate (lb$_m$/s)	4.5	4.3	4.5	4.4	4.5	4.6	4.4	4.1	4.5	4.5	4.3	4.4
20% venturi inlet P (psia) [PT0364]	351	346	350	356	351	354	347	351	349	349	335	352
20% venturi inlet T (F) [TT0364]	-269	-267	-270	-269	-270	-272	-268	-253	-269	-269	-262	-261
20% venturi throat P (psia) [PT0361]	41	48	44	43	42	41	47	70	49	44	67	62
20% venturi ACd (in^2)	0.01154	0.01154	0.01154	0.01154	0.01154	0.01154	0.01154	0.01154	0.01154	0.01154	0.01154	0.01154
20% venturi flow rate (lb$_m$/s)	1.1	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1	1.1	1.0	1.0
LOX flow rate (lb$_m$/s), high thrust side	5.5	5.4	5.7	5.7	5.6	5.7	5.4	5.0	5.6	5.6	5.4	5.2
LOX flow rate (lb$_m$/s), low thrust side	5.6	5.3	5.6	5.5	5.6	5.7	5.4	5.1	5.6	5.6	5.3	5.4
Fuel System												
Tanks (psia) [PT0101]	5115	4890	5268	3362	4831	4326	4902	3786	4410	3399	4529	3639
Supply d/s of valve (psia) [PT0102]	593	16	593	591	592	589	593	589	566	578	593	589
100% venturi inlet P (psig) [PT0160]	457	5	458	457	459	458	459	452	437	452	457	454
100% venturi inlet T (F) [TT0160]	75	60	83	51	75	69	90	79	69	55	94	81
100% venturi ACd (in^2)	0.3575	0.3575	0.3575	0.3575	0.3575	0.3575	0.3575	0.3575	0.3575	0.3575	0.3575	0.3575
100% venturi flow rate (lb$_m$/s)	1.53	n/a	1.52	1.57	1.54	1.54	1.52	1.51	1.48	1.54	1.51	1.51
80% venturi inlet P (psig) [PT0163]	444	-10	439	439	446	447	451	447	430	449	485	481
80% venturi inlet T (F) [TT0163]	72	55	80	46	71	65	86	75	67	50	89	76
80% venturi ACd (in^2)	0.2816	0.2816	0.2816	0.2816	0.2816	0.2816	0.2816	0.2816	0.2816	0.2816	0.2816	0.2816
80% venturi flow rate (lb$_m$/s)	1.18	n/a	1.16	1.19	1.18	1.19	1.18	1.18	1.15	1.21	1.26	1.27
20% venturi inlet P (psig) [PT0164]	452	-3	461	458	465	462	465	465	444	458	462	462
20% venturi inlet T (F) [TT0164]	75	58	84	49	72	67	89	79	68	52	90	77
20% venturi ACd (in^2)	0.07559	0.07559	0.07559	0.07559	0.07559	0.07559	0.07559	0.07559	0.07559	0.07559	0.07559	0.07559
20% venturi flow rate (lb$_m$/s)	0.32	n/a	0.32	0.33	0.33	0.33	0.33	0.33	0.32	0.33	0.32	0.33
Fuel flow rate (lb$_m$/s), high thrust side	1.53	n/a	1.52	1.57	1.54	1.54	1.52	1.51	1.48	1.54	1.51	1.51
Fuel flow rate (lb$_m$/s), low thrust side	1.50	n/a	1.48	1.53	1.51	1.52	1.50	1.51	1.46	1.55	1.58	1.59
TTEB System												
Supply P to engine (psia) [PT0651]	596	594	596	599	594	610	588	599	593	601	588	620
TTEB density (lb$_m$/ft3)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Orifice to each thruster (in)	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
flow rate to each thruster (lb$_m$/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Water System												
Tank P (psia) [PT0401]	781	781	777	771	779	777	769	777	780	777	773	772
Engine inlet P (psia) [PT0451]	624	677	619	626	617	643	605	610	607	602	606	602
Engine exit P (psia) [PT0453]	178	96	180	167	182	157	198	188	195	191	195	196
Engine ΔP (psi)	446	581	439	459	435	486	407	422	412	411	411	406
Engine inlet T (F) [TT0451]	45	44	56	54	54	52	61	63	59	57	78	77
Engine exit T (F) [TT0453]	38	35	47	48	47	44	54	56	51	51	70	70
min. initial engine exit T (F) [TT0453]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Engine ΔT (F) relative to TT0453	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
High Thrust Side Ramp												
Upper T (F) [TT0455]	51	50	58	59	59	58	65	69	63	63	75	71
Lower T (F) [TT0456]	50	50	59	58	59	57	66	68	63	63	75	75
Low Thrust Side Ramp												
Upper T (F) [TT0457]	43	44	51	53	51	50	60	60	56	56	83	82
Lower T (F) [TT0458]	43	41	51	51	53	51	59	59	57	57	83	81
Total water flow rate (lb$_m$/s)***	36.1	26.5	35.2	33.7	35.6	32.4	40.5	36.2	40.8	40.7	40.7	40.5

* GHe used in fuel/TTEB systems ** Ignition test - GHe used in fuel system *** est. w/engine ΔP when F/M inop ^ LN2/GHe used for LOX/GH2

Table 10. Summary of LASRE system performance (Continued).

Test #	GRUN0020*		GRUN0019*	
Test date	9/1/96		7/26/96	
Test Objective	Gd. cold flow		Gd. cold flow	
Blow #	1	2	1	2
LOX System				
ave. tank P (psia) [PT0302 & PT0301]	363	---	363	370
100% venturi inlet P (psia) [PT0360]	353	---	351	336
100% venturi inlet T (F) [TT0360]	-265	---	assume -275	
100% venturi ACd (in^2)	0.0609	0.0609	0.0609	0.0609
100% venturi flow rate (lb$_m$/s)	5.6	---	5.8	5.6
80% venturi inlet P (psia) [PT0363]	340	---	343	334
80% venturi inlet T (F) [TT0363]	-270	---	-273	-276
80% venturi throat P (psia) [PT0362]	25	---	38	22
80% venturi ACd (in^2)	0.0473	0.0473	0.0473	0.0473
80% venturi flow rate (lb$_m$/s)	4.4	---	4.6	4.6
20% venturi inlet P (psia) [PT0364]	343	---	347	337
20% venturi inlet T (F) [TT0364]	-267	---	-279	-270
20% venturi throat P (psia) [PT0361]	41	---	55	31
20% venturi ACd (in^2)	0.01154	0.01154	0.01154	0.01154
20% venturi flow rate (lb$_m$/s)	1.1	---	1.1	1.1
LOX flow rate (lb$_m$/s), high thrust side	5.6	---	5.8	5.6
LOX flow rate (lb$_m$/s), low thrust side	5.5	---	5.7	5.7
Fuel System				
Tanks (psia) [PT0101]	5312	---	4713	3698
Supply d/s of valve (psia) [PT0102]	320	---	581	577
100% venturi inlet P (psig) [PT0160]	247	---	452	457
100% venturi inlet T (F) [TT0160]	113	---	97	80
100% venturi ACd (in^2)	0.3575	0.3575	0.3575	0.3575
100% venturi flow rate (lb$_m$/s)	0.82	---	1.49	1.52
80% venturi inlet P (psig) [PT0163]	261	---	469	463
80% venturi inlet T (F) [TT0163]	107	---	100	83
80% venturi ACd (in^2)	0.2816	0.2816	0.2816	0.2816
80% venturi flow rate (lb$_m$/s)	0.69	---	1.21	1.21
20% venturi inlet P (psig) [PT0164]	242	---	447	455
20% venturi inlet T (F) [TT0164]	111	---	97	83
20% venturi ACd (in^2)	0.07559	0.07559	0.07559	0.07559
20% venturi flow rate (lbm/s)	0.17	---	0.31	0.32
Fuel flow rate (lb$_m$/s), high thrust side	0.82	---	1.49	1.52
Fuel flow rate (lb$_m$/s), low thrust side	0.86	---	1.52	1.53
TTEB System				
Supply P to engine (psia) [PT0651]	592	---	568	25
TTEB density (lb$_m$/ft^3)	n/a	---	n/a	n/a
Orifice to each thruster (in)	0.026	0.026	0.026	0.026
flow rate to each thruster (lb$_m$/s)	n/a	---	n/a	n/a
Water System				
Tank P (psia) [PT0401]	781	---	774	766
Engine inlet P (psia) [PT0451]	579	---	574	556
Engine exit P (psia) [PT0453]	190	---	197	179
Engine ΔP (psi)	389	---	377	377
Engine inlet T (F) [TT0451]	87	---	91	92
Engine exit T (F) [TT0453]	78	---	83	84
min. initial engine exit T (F) [TT0453]	n/a	---	n/a	n/a
Engine ΔT (F) relative to TT0453	n/a	---	n/a	n/a
High Thrust Side Ramp				
Upper T (F) [TT0455]	89	---	90	89
Lower T (F) [TT0456]	89	---	100	99
Low Thrust Side Ramp				
Upper T (F) [TT0457]	82	---	88	88
Lower T (F) [TT0458]	83	---	90	88
Total water flow rate (lb$_m$/s)***	39.6	---	39.6	39.6

* GHe used in fuel/TTEB systems   ** Ignition test - GHe used in fuel system   *** est. w/engine ΔP when F/M inop   ^ LN2/GHe used for LOX/GH2

Table 11. Summary of LASRE engine performance.

Test #		GRUN0057*		GRUN0056^	GRUN0055^		GRUN0054^		GRUN0052^	FLT0050*	FLT0049**
Test date		9/18/98		9/11/98	8/19/98		8/14/98		7/30/98	7/23/98	4/15/98
Test Objective		Flt. cold flow		Flt. cold flow	Flt. cold flow		Flt. cold flow		Flt. cold flow	Flt. cold flow	Flt. cold flow
Blow #		1	2	2	1	2	1	2	1	1	1
HIGH Thrust Side											
TH#1	LOX mfd P (psia) [PT0352]	195	191	203	216	216	208	203	198	200	192
	LOX mfd T (F) [TT0352]	-248	-249	-273	inop	inop	inop	inop	inop	inop	inop
	Fuel mfd P (psig) [PT0152]	247	247	248	248	249	247	249	248	252	237
	Fuel mfd T (F) [TT0152]	55	29	55	55	30	63	32	37	48	42
	Pc (psig) [PT0001]	34	35	34	31	31	35	34	32	36	31
	LOX side density (lb_m/ft^3)	62	63	43	43	43	43	43	43	63	63
	LOX side flow rate (lb_m/s)	1.50	1.48	1.46	1.45	1.45	1.43	1.40	1.43	1.47	1.50
	LOX side ACd (in^2)	0.024	0.023	0.027	0.025	0.025	0.026	0.026	0.026	0.022	0.023
	Fuel side flow rate (lb_m/s)	0.41	0.41	0.41	0.41	0.41	0.40	0.41	0.41	0.39	0.40
	Fuel side ACd (in^2)	0.168	0.164	0.167	0.167	0.164	0.168	0.164	0.164	0.165	0.178
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TH#2	LOX mfd P (psia) [PT0353]	196	192	196	219	216	207	203	195	201	191
	LOX mfd T (F) [TT0353]	-259	-259	-280	-277	-282	-278	-279	-280	-257	-255
	Fuel mfd P (psig) [PT0153]	243	242	244	241	242	241	244	245	243	239
	Pc (psig) [PT0002]	29	31	30	28	29	30	29	29	31	31
	LOX side density (lb_m/ft^3)	64	63	43	43	43	43	43	43	63	63
	LOX side flow rate (lb_m/s)	1.50	1.48	1.46	1.45	1.45	1.43	1.40	1.43	1.47	1.50
	LOX side ACd (in^2)	0.023	0.023	0.027	0.025	0.025	0.026	0.025	0.026	0.021	0.023
	Fuel side flow rate (lb_m/s)	0.41	0.41	0.41	0.41	0.41	0.40	0.41	0.41	0.39	0.40
	Fuel side ACd (in^2)	0.171	0.168	0.170	0.171	0.169	0.172	0.167	0.166	0.171	0.176
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TH#3	LOX mfd P (psia) [PT0354]	194	193	198	219	213	206	204	197	200	194
	LOX mfd T (F) [TT0354]	-263	-265	-287	-287	-287	-281	-285	-286	-261	-261
	Fuel mfd P (psig) [PT0154]	246	244	248	243	246	246	243	246	248	243
	Pc (psig) [PT0003]	28	29	31	27	28	29	27	27	29	29
	LOX side density (lb_m/ft^3)	65	63	43	45	45	45	45	45	63	63
	LOX side flow rate (lb_m/s)	1.50	1.48	1.46	1.45	1.45	1.43	1.40	1.43	1.47	1.50
	LOX side ACd (in^2)	0.023	0.023	0.027	0.024	0.025	0.025	0.025	0.026	0.021	0.022
	Fuel side flow rate (lb_m/s)	0.41	0.41	0.41	0.41	0.41	0.40	0.41	0.41	0.39	0.40
	Fuel side ACd (in^2)	0.168	0.166	0.167	0.170	0.166	0.169	0.168	0.165	0.168	0.174
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TH#4	LOX mfd P (psia) [PT0355]	196	193	205	221	213	208	208	201	196	200
	LOX mfd T (F) [TT0355]	-263	-265	-288	-285	-286	-281	-282	-283	-262	-262
	Fuel mfd P (psig) [PT0155]	250	247	251	249	250	250	247	250	255	242
	Pc (psig) [PT0004]	31	30	32	28	29	31	27	30	31	29
	LOX side density (lb_m/ft^3)	65	63	44	44	44	44	44	44	63	63
	LOX side flow rate (lb_m/s)	1.50	1.48	1.46	1.45	1.45	1.43	1.40	1.43	1.47	1.50
	LOX side ACd (in^2)	0.023	0.023	0.026	0.024	0.025	0.025	0.024	0.026	0.022	0.022
	Fuel side flow rate (lb_m/s)	0.41	0.41	0.41	0.41	0.41	0.40	0.41	0.41	0.39	0.40
	Fuel side ACd (in^2)	0.166	0.164	0.165	0.166	0.164	0.166	0.165	0.163	0.163	0.174
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
HIGH thrust side ave. Pc (psig)		30	31	31	29	29	31	29	30	32	30
HIGH thrust side ave. MR		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
HIGH thrust side ave. C*, eff. (%)		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

* GHe used on fuel side ** Ignition test *** instrumentation questionable ^LN2/GHe used for LOX/GH2

Table 11. Summary of LASRE engine performance (Continued).

	Test #	GRUN0057*		GRUN0056^	GRUN0055^		GRUN0054^		GRUN0052^	FLT0050*	FLT0049**
	Test date	9/18/98		9/11/98	8/19/98		8/14/98		7/30/98	7/23/98	4/15/98
	Test Objective	Flt. cold flow		Flt. cold flow	Flt. cold flow		Flt. cold flow		Flt. cold flow	Flt. cold flow	Flt. cold flow
	Blow #	1	2	2	1	2	1	2	1	1	1
	LOW Thrust Side										
TH#5	LOX mfd P (psia) [PT0356]	203	196	204	235	226	218	217	203	201	204
	Fuel mfd P (psig) [PT0156]	246	246	248	247	253	251	246	244	252	245
	Fuel mfd T (F) [TT0156]	inop	inop	inop	inop	inop	72	inop	46	56	50
	Pc (psig) [PT0005]	36	34	34	31	31	34	31	33	35	32
	LOX side density (lb_m/ft^3)	64	63	43	43	43	43	43	43	63	63
	LOX side flow rate (lb_m/s)	1.45	1.43	1.38	1.35	1.40	1.33	1.35	1.35	1.46	1.43
	LOX side ACd (in^2)	0.022	0.022	0.025	0.022	0.024	0.023	0.023	0.025	0.022	0.021
	Fuel side flow rate (lb_m/s)	0.41	0.41	0.41	0.40	0.41	0.40	0.41	0.41	0.40	0.40
	Fuel side ACd (in^2)	0.170	0.168	0.169	0.168	0.163	0.167	0.167	0.168	0.167	0.174
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TH#6	LOX mfd P (psia) [PT0357]	205	194	201	232	229	217	211	203	200	196
	LOX mfd T (F) [TT0357]	-258	-257	-279	-278	-281	-273	-278	-278	-256	-253
	Fuel mfd P (psig) [PT0157]	244	242	243	241	246	245	244	239	247	241
	Pc (psig) [PT0006]	29	29	28	28	27	29	26	27	30	30
	LOX side density (lb_m/ft^3)	64	63	43	43	43	43	43	43	63	63
	LOX side flow rate (lb_m/s)	1.45	1.43	1.38	1.35	1.40	1.33	1.35	1.35	1.46	1.43
	LOX side ACd (in^2)	0.021	0.022	0.025	0.022	0.023	0.023	0.024	0.024	0.021	0.021
	Fuel side flow rate (lb_m/s)	0.41	0.41	0.41	0.40	0.41	0.40	0.41	0.41	0.40	0.40
	Fuel side ACd (in^2)	0.172	0.170	0.172	0.172	0.168	0.171	0.168	0.172	0.171	0.176
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TH#7	LOX mfd P (psia) [PT0358]	204	194	201	229	225	212	214	203	194	191
	Fuel mfd P (psig) [PT0158]	240	235	236	234	238	242	240	236	242	237
	Pc (psig) [PT0007]	28	26	26	27	29	27	27	27	28	29
	LOX side density (lb_m/ft^3)	64.5	63	44	44	44	44	44	44	63	63
	LOX side flow rate (lb_m/s)	1.45	1.43	1.38	1.35	1.40	1.33	1.35	1.35	1.46	1.43
	LOX side ACd (in^2)	0.021	0.022	0.025	0.022	0.023	0.023	0.023	0.024	0.022	0.021
	Fuel side flow rate (lb_m/s)	0.41	0.41	0.41	0.40	0.41	0.40	0.41	0.41	0.40	0.40
	Fuel side ACd (in^2)	0.174	0.175	0.177	0.177	0.173	0.173	0.171	0.173	0.175	0.180
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TH#8	LOX mfd P (psia) [PT0359]	209	201	211	233	230	215	213	210	204	198
	LOX mfd T (F) [TT0359]	-260	-263	-283	-280	-285	-278	-276	-278	-258	-258
	Fuel mfd P (psig) [PT0159]	247	246	244	241	243	250	248	243	246	247
	Pc (psig) [PT0008]	30	30	30	28	30	29	30	29	30	32
	LOX side density (lb_m/ft^3)	64.5	63	44	44	44	44	44	44	63	63
	LOX side flow rate (lb_m/s)	1.45	1.43	1.38	1.35	1.40	1.33	1.35	1.35	1.46	1.43
	LOX side ACd (in^2)	0.021	0.021	0.024	0.022	0.023	0.023	0.023	0.024	0.021	0.021
	Fuel side flow rate (lb_m/s)	0.41	0.41	0.41	0.40	0.41	0.40	0.41	0.41	0.40	0.40
	Fuel side ACd (in^2)	0.170	0.168	0.171	0.172	0.170	0.168	0.166	0.169	0.171	0.172
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	31	31	31	31	31	31	31	31	31	31
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
LOW thrust side ave. Pc (psig)		31	30	29	28	29	30	28	29	31	31
LOW thrust side ave. MR		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
LOW thrust side ave. C*, eff. (%)		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

* GHe used on fuel side ** Ignition test *** instrumentation questionable ^LN2/GHe used for LOX/GH2

Table 11. Summary of LASRE engine performance (Continued).

Test #		FLT0048^	FLT0047^	GRUN0046^		GRUN0041^	GRUN0038^	GRUN0037	GRUN0036	GRUN0035*
Test date		3/19/98	3/4/98	2/12/98		12/9/97	9/24/97	4/30/97	4/23/97	4/16/97
Test Objective		Flt. cold flow		Flt. cold flow		Flt. cold flow	Flt. cold flow	Gd. hot fire	Gd. hot fire	Gd. cold flow
Blow #		1	1	1	2	2	1	1	1	1
HIGH Thrust Side										
TH#1	LOX mfd P (psia) [PT0352]	193	198	201	210	225	202	309	306	204
	LOX mfd T (F) [TT0352]	inop	inop	inop	inop	-262	-271	-248	-246	-241
	Fuel mfd P (psig) [PT0152]	243	244	245	238	239	241	307	305	220
	Fuel mfd T (F) [TT0152]	53	43	49	54	73	35	18	10	50
	Pc (psig) [PT0001]	32	29	29	32	27	28	217	218	34
	LOX side density (lb_m/ft^3)	43	43	43	43	39	41	62	62	60
	LOX side flow rate (lb_m/s)	1.45	1.45	1.43	1.45	1.40	1.45	1.48	1.50	1.48
	LOX side ACd (in^2)	0.026	0.026	0.026	0.026	0.025	0.027	0.032	0.033	0.023
	Fuel side flow rate (lb_m/s)	0.40	0.39	0.41	0.40	0.40	0.41	0.26	0.26	0.39
	Fuel side ACd (in^2)	0.173	0.171	0.171	0.173	0.172	0.168	0.136	0.141	0.177
	MR	n/a	n/a	n/a	n/a	n/a	n/a	5.7	5.7	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	7509	7408	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	98	97	n/a
TH#2	LOX mfd P (psia) [PT0353]	199	199	200	212	227	200	307	307	201
	LOX mfd T (F) [TT0353]	-280	-282	-277	-275	-270	-282	-253	-256	-249
	Fuel mfd P (psig) [PT0153]	238	237	242	233	230	235	304	304	215
	Pc (psig) [PT0002]	29	27	28	29	29	27	210	210	29
	LOX side density (lb_m/ft^3)	43	43	43	42	41	44	63	64	62
	LOX side flow rate (lb_m/s)	1.45	1.45	1.43	1.45	1.40	1.45	1.48	1.50	1.48
	LOX side ACd (in^2)	0.026	0.025	0.026	0.026	0.024	0.026	0.031	0.031	0.022
	Fuel side flow rate (lb_m/s)	0.40	0.39	0.41	0.40	0.40	0.41	0.26	0.26	0.39
	Fuel side ACd (in^2)	0.176	0.176	0.173	0.176	0.179	0.172	0.135	0.137	0.180
	MR	n/a	n/a	n/a	n/a	n/a	n/a	5.7	5.7	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	7277	7148	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	95	93	n/a
TH#3	LOX mfd P (psia) [PT0354]	199	196	200	212	231	199	311	312	205
	LOX mfd T (F) [TT0354]	-287	-289	-287	-285	-274	-289	-262	-264	-261
	Fuel mfd P (psig) [PT0154]	240	236	239	232	231	238	305	303	216
	Pc (psig) [PT0003]	30	29	29	31	28	28	209	210	30
	LOX side density (lb_m/ft^3)	45	45	45	44	42	45	65.1	65.5	65
	LOX side flow rate (lb_m/s)	1.45	1.45	1.43	1.45	1.40	1.45	1.48	1.50	1.48
	LOX side ACd (in^2)	0.025	0.025	0.025	0.025	0.024	0.026	0.029	0.030	0.022
	Fuel side flow rate (lb_m/s)	0.40	0.39	0.41	0.40	0.40	0.41	0.26	0.26	0.39
	Fuel side ACd (in^2)	0.175	0.176	0.175	0.177	0.178	0.170	0.135	0.139	0.180
	MR	n/a	n/a	n/a	n/a	n/a	n/a	5.7	5.7	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	7244	7148	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	95	93	n/a
TH#4	LOX mfd P (psia) [PT0355]	201	203	201	214	238	201	321	319	211
	LOX mfd T (F) [TT0355]	-285	-285	-285	-281	-275	-287	-262	-263	-256
	Fuel mfd P (psig) [PT0155]	243	243	242	238	238	240	308	308	221
	Pc (psig) [PT0004]	30	29	29	31	31	30	214	212	30
	LOX side density (lb_m/ft^3)	44	44	44	44	42	45	65.1	65.3	64
	LOX side flow rate (lb_m/s)	1.45	1.45	1.43	1.45	1.40	1.45	1.48	1.50	1.48
	LOX side ACd (in^2)	0.025	0.025	0.026	0.025	0.023	0.026	0.029	0.029	0.021
	Fuel side flow rate (lb_m/s)	0.40	0.39	0.41	0.40	0.40	0.41	0.26	0.26	0.39
	Fuel side ACd (in^2)	0.173	0.172	0.173	0.173	0.173	0.169	0.134	0.135	0.176
	MR	n/a	n/a	n/a	n/a	n/a	n/a	5.7	5.7	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	7410	7213	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	97	94	n/a
HIGH thrust side ave. Pc (psig)		30	28	29	31	29	28	212	213	31
HIGH thrust side ave. MR		n/a	n/a	n/a	n/a	n/a	n/a	5.7	5.7	n/a
HIGH thrust side ave. C*, eff. (%)		n/a	n/a	n/a	n/a	n/a	n/a	96	94	n/a

* GHe used on fuel side ** Ignition test *** instrumentation questionable ^LN2/GHe used for LOX/GH2

Table 11. Summary of LASRE engine performance (Continued).

	Test #	FLT0048^	FLT0047^	GRUN0046^		GRUN0041^	GRUN0038^	GRUN0037	GRUN0036	GRUN0035*
	Test date	**3/19/98**	**3/4/98**	**2/12/98**		**12/9/97**	**9/24/97**	**4/30/97**	**4/23/97**	**4/16/97**
	Test Objective	**Flt. cold flow**	**Flt. cold flow**	**Flt. cold flow**		**Flt. cold flow**	**Flt. cold flow**	**Gd. hot fire**	**Gd. hot fire**	**Gd. cold flow**
	Blow #	**1**	**1**	**1**	**2**	**2**	**1**	**1**	**1**	**1**
	LOW Thrust Side									
TH#5	LOX mfd P (psia) [PT0356]	210	206	206	212	225	204	303	297	209
	Fuel mfd P (psig) [PT0156]	254	246	250	249	244	252	n/a	n/a	n/a
	Fuel mfd T (F) [TT0156]	60	53	59	63	79	45	31	23	59
	Pc (psig) [PT0005]	33	33	32	32	31	31	205	205	33
	LOX side density (lb$_m$/ft^3)	43	43	43	42	40	43	63	63	62
	LOX side flow rate (lb$_m$/s)	1.38	1.38	1.35	1.38	1.33	1.38	1.40	1.43	1.40
	LOX side ACd (in^2)	0.024	0.024	0.024	0.025	0.023	0.025	0.029	0.031	0.021
	Fuel side flow rate (lb$_m$/s)	0.40	0.40	0.41	0.41	0.40	0.41	0.26	0.27	0.39
	Fuel side ACd (in^2)	0.169	0.173	0.168	0.168	0.171	0.164	n/a	n/a	n/a
	MR	n/a	n/a	n/a	n/a	n/a	n/a	5.4	5.4	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	7420	7288	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	96	94	n/a
TH#6	LOX mfd P (psia) [PT0357]	200	208	209	216	220	204	302	299	204
	LOX mfd T (F) [TT0357]	-280	-281	-277	-274	-267	-278	-250	-253	-248
	Fuel mfd P (psig) [PT0157]	247	244	244	243	237	245	298	296	227
	Pc (psig) [PT0006]	28	28	26	27	27	27	200	199	29
	LOX side density (lb$_m$/ft^3)	43	43	43	42	40	43	63	63	62
	LOX side flow rate (lb$_m$/s)	1.38	1.38	1.35	1.38	1.33	1.38	1.40	1.43	1.40
	LOX side ACd (in^2)	0.024	0.024	0.024	0.024	0.023	0.025	0.028	0.029	0.021
	Fuel side flow rate (lb$_m$/s)	0.40	0.40	0.41	0.41	0.40	0.41	0.26	0.27	0.39
	Fuel side ACd (in^2)	0.174	0.175	0.172	0.172	0.175	0.169	0.140	0.142	0.174
	MR	n/a	n/a	n/a	n/a	n/a	n/a	5.4	5.4	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	7247	7085	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	94	91	n/a
TH#7	LOX mfd P (psia) [PT0358]	199	203	206	213	228	203	300	297	206
	Fuel mfd P (psig) [PT0158]	240	237	236	235	233	241	296	294	223
	Pc (psig) [PT0007]	27	27	27	26	26	26	198	197	31
	LOX side density (lb$_m$/ft^3)	44	44	44	43	42	43	64	64	63
	LOX side flow rate (lb$_m$/s)	1.38	1.38	1.35	1.38	1.33	1.38	1.40	1.43	1.40
	LOX side ACd (in^2)	0.024	0.024	0.024	0.024	0.022	0.025	0.028	0.029	0.021
	Fuel side flow rate (lb$_m$/s)	0.40	0.40	0.41	0.41	0.40	0.41	0.26	0.27	0.39
	Fuel side ACd (in^2)	0.178	0.179	0.177	0.178	0.178	0.172	0.140	0.143	0.177
	MR	n/a	n/a	n/a	n/a	n/a	n/a	5.4	5.4	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	7178	7017	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	93	91	n/a
TH#8	LOX mfd P (psia) [PT0359]	209	209	210	221	235	212	305	298	205
	LOX mfd T (F) [TT0359]	-283	-279	-281	-277	-273	-283	-256	-258	-253
	Fuel mfd P (psig) [PT0159]	244	245	247	244	241	248	301	300	229
	Pc (psig) [PT0008]	29	31	31	31	29	30	202	201	33
	LOX side density (lb$_m$/ft^3)	44	44	44	43	42	44	64	64	63
	LOX side flow rate (lb$_m$/s)	1.38	1.38	1.35	1.38	1.33	1.38	1.40	1.43	1.40
	LOX side ACd (in^2)	0.023	0.023	0.024	0.024	0.022	0.024	0.028	0.029	0.021
	Fuel side flow rate (lb$_m$/s)	0.40	0.40	0.41	0.41	0.40	0.41	0.26	0.27	0.39
	Fuel side ACd (in^2)	0.175	0.173	0.170	0.172	0.173	0.167	0.139	0.140	0.172
	MR	n/a	n/a	n/a	n/a	n/a	n/a	5.4	5.4	n/a
	actual C* (ft/s)	31	31	n/a	n/a	n/a	n/a	7316	7153	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	94	92	n/a
LOW thrust side ave. Pc (psig)		29	30	29	29	28	29	201	201	32
LOW thrust side ave. MR		n/a	n/a	n/a	n/a	n/a	n/a	5.4	5.4	n/a
LOW thrust side ave. C*, eff. (%)		n/a	n/a	n/a	n/a	n/a	n/a	94	92	n/a

* GHe used on fuel side ** Ignition test *** instrumentation questionable ^LN2/GHe used for LOX/GH2

Table 11. Summary of LASRE engine performance (Continued).

	Test #	GRUN0033**				GRUN0032**		GRUN0031**		GRUN0030*	GRUN0029*	GRUN0028*
	Test date	2/6/97				1/31/97		1/23/97		1/18/97	12/17/96	12/11/96
	Test Objective	Ignition test				Ignition test		Ignition test		Gd. cold flow	Gd. cold flow	Gd. cold flow
	Blow #	1-ign	1-main	2-ign	2-main	1-ign	1-main	1-ign	1-main	1	1	1
	HIGH Thrust Side											
TH#1	LOX mfd P (psia) [PT0352]	261	201	241	193	249	235	261	193	196	201	195
	LOX mfd T (F) [TT0352]	-230	-246	-224	-243	-229	-219	-232	-248	-248	-249	-250
	Fuel mfd P (psig) [PT0152]	31	230	31	237	7	210	28	212	197	195	198
	Fuel mfd T (F) [TT0152]	133	58	334	49	63	64	177	47	40	51	65
	Pc (psig) [PT0001]	34	36	37	32	13	21	32	35	31	32	33
	LOX side density (lb$_m$/ft^3)	58	62	57	61	n/a	n/a	58	62	62	62	62
	LOX side flow rate (lb$_m$/s)	1.45	1.48	1.43	1.45	0.75	1.00	1.45	1.48	1.48	1.48	1.50
	LOX side ACd (in^2)	n/a	0.023	n/a	0.023	n/a	n/a	n/a	0.023	0.023	0.023	0.023
	Fuel side flow rate (lb$_m$/s)	n/a	0.39	n/a	0.39	n/a	0.38	n/a	0.39	0.40	0.39	0.39
	Fuel side ACd (in^2)	n/a	0.173	n/a	0.167	n/a	0.186	n/a	0.185	0.200	0.201	0.202
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TH#2	LOX mfd P (psia) [PT0353]	260	194	243	194	249	231	257	195	189	198	194
	LOX mfd T (F) [TT0353]	-233	-255	-233	-253	-229	-214	-232	-255	-253	-256	-256
	Fuel mfd P (psig) [PT0153]	20	229	26	230	1	202	26	206	188	192	194
	Pc (psig) [PT0002]	35	33	36	30	11	16	30	30	29	30	30
	LOX side density (lb$_m$/ft^3)	58	63	58	63	n/a	n/a	58	63	63	63	64
	LOX side flow rate (lb$_m$/s)	1.45	1.48	1.43	1.45	0.75	1.00	1.45	1.48	1.48	1.48	1.50
	LOX side ACd (in^2)	n/a	0.023	n/a	0.022	n/a	n/a	n/a	0.023	0.023	0.022	0.023
	Fuel side flow rate (lb$_m$/s)	n/a	0.39	n/a	0.39	n/a	0.38	n/a	0.39	0.40	0.39	0.39
	Fuel side ACd (in^2)	n/a	0.173	n/a	0.172	n/a	0.193	n/a	0.190	0.209	0.204	0.206
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TH#3	LOX mfd P (psia) [PT0354]	264	196	245	195	241	220	252	199	199	206	201
	LOX mfd T (F) [TT0354]	-239	-262	-244	-259	-239	-240	-238	-263	-262	-263	-262
	Fuel mfd P (psig) [PT0154]	30	225	30	231	8	207	27	209	192	190	190
	Pc (psig) [PT0003]	33	31	36	33	10	14	32	29	31	29	31
	LOX side density (lb$_m$/ft^3)	60	65	61	64	n/a	n/a	60	65	65	65	65
	LOX side flow rate (lb$_m$/s)	1.45	1.48	1.43	1.45	0.75	1.00	1.45	1.48	1.48	1.48	1.50
	LOX side ACd (in^2)	n/a	0.022	0.020	0.022	n/a	n/a	n/a	0.022	0.022	0.021	0.022
	Fuel side flow rate (lb$_m$/s)	n/a	0.39	n/a	0.39	n/a	0.38	n/a	0.39	0.40	0.39	0.39
	Fuel side ACd (in^2)	n/a	0.176	n/a	0.171	n/a	0.189	n/a	0.187	0.205	0.206	0.210
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TH#4	LOX mfd P (psia) [PT0355]	271	203	248	203	265	243	268	209	205	205	198
	LOX mfd T (F) [TT0355]	-242	-261	-248	-263	-242	-240	-241	-265	-260	-264	-264
	Fuel mfd P (psig) [PT0155]	31	235	31	238	11	213	31	212	194	195	194
	Pc (psig) [PT0004]	34	31	36	29	7	13	33	30	30	28	31
	LOX side density (lb$_m$/ft^3)	61	65	62	65	n/a	n/a	60	65	64.5	65	65
	LOX side flow rate (lb$_m$/s)	1.45	1.48	1.43	1.45	0.75	1.00	1.45	1.48	1.48	1.48	1.50
	LOX side ACd (in^2)	0.019	0.022	0.019	0.021	n/a	n/a	0.019	0.021	0.022	0.021	0.023
	Fuel side flow rate (lb$_m$/s)	n/a	0.39	n/a	0.39	n/a	0.38	n/a	0.39	0.40	0.39	0.39
	Fuel side ACd (in^2)	n/a	0.169	n/a	0.167	n/a	0.184	n/a	0.185	0.203	0.201	0.206
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
HIGH thrust side ave. Pc (psig)		34	33	36	31	10	16	32	31	30	30	31
HIGH thrust side ave. MR		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
HIGH thrust side ave. C*, eff. (%)		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

* GHe used on fuel side ** Ignition test *** instrumentation questionable ^LN2/GHe used for LOX/GH2

Table 11. Summary of LASRE engine performance (Continued).

	Test #	GRUN0033**				GRUN0032**		GRUN0031**		GRUN0030*	GRUN0029*	GRUN0028*
	Test date	2/6/97				1/31/97		1/23/97		1/18/97	12/17/96	12/11/96
	Test Objective	Ignition test				Ignition test		Ignition test		Gd. cold flow	Gd. cold flow	Gd. cold flow
	Blow #	1-ign	1-main	2-ign	2-main	1-ign	1-main	1-ign	1-main	1	1	1
	HIGH Thrust Side											
TH#5	LOX mfd P (psia) [PT0356]	228	203	229	200	286	244	228	198	203	201	197
	Fuel mfd P (psig) [PT0156]	29	235	33	239	7	230	29	213	206	207	207
	Fuel mfd T (F) [TT0156]	63	68	56	58	203	75	59	55	50	53	67
	Pc (psig) [PT0005]	13	33	29	33	9	17	29	31	31	29	31
	LOX side density (lb_m/ft^3)	59	63	60	62	n/a	n/a	60	64	63	63	63
	LOX side flow rate (lb_m/s)	1.43	1.43	1.35	1.40	0.78	0.91	1.38	1.43	1.43	1.40	1.43
	LOX side ACd (in^2)	n/a	0.022	0.019	0.022	n/a	n/a	n/a	0.022	0.021	0.021	0.022
	Fuel side flow rate (lb_m/s)	n/a	0.40	n/a	0.40	n/a	0.39	n/a	0.39	0.40	0.40	0.39
	Fuel side ACd (in^2)	n/a	0.173	n/a	0.170	n/a	0.175	n/a	0.187	0.195	0.193	0.191
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TH#6	LOX mfd P (psia) [PT0357]	228	202	225	200	274	244	223	204	203	203	195
	LOX mfd T (F) [TT0357]	-237	-252	-240	-250	-233	-239	-238	-256	-252	-253	-255
	Fuel mfd P (psig) [PT0157]	25	226	30	234	10	215	28	205	199	199	199
	Pc (psig) [PT0006]	30	29	28	27	9	13	30	28	27	26	29
	LOX side density (lb_m/ft^3)	59	63	60	62	n/a	n/a	60	64	63	63	63
	LOX side flow rate (lb_m/s)	1.43	1.43	1.35	1.40	0.78	0.91	1.38	1.43	1.43	1.40	1.43
	LOX side ACd (in^2)	n/a	0.021	0.019	0.021	n/a	n/a	n/a	0.021	0.021	0.021	0.022
	Fuel side flow rate (lb_m/s)	n/a	0.40	n/a	0.40	n/a	0.39	n/a	0.39	0.40	0.40	0.39
	Fuel side ACd (in^2)	n/a	0.180	n/a	0.173	n/a	0.187	n/a	0.194	0.201	0.200	0.198
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TH#7	LOX mfd P (psia) [PT0358]	229	201	230	196	267	228	216	203	199	202	194
	Fuel mfd P (psig) [PT0158]	21	225	20	225	3	208	25	199	195	197	192
	Pc (psig) [PT0007]	31	31	32	32	11	14	30	29	30	29	33
	LOX side density (lb_m/ft^3)	61	64.5	61	63	n/a	n/a	62	64.5	64	64.5	64.5
	LOX side flow rate (lb_m/s)	1.43	1.43	1.35	1.40	0.78	0.91	1.38	1.43	1.43	1.40	1.43
	LOX side ACd (in^2)	n/a	0.021	0.019	0.022	n/a	n/a	n/a	0.021	0.021	0.021	0.022
	Fuel side flow rate (lb_m/s)	n/a	0.40	n/a	0.40	n/a	0.39	n/a	0.39	0.40	0.40	0.39
	Fuel side ACd (in^2)	n/a	0.180	n/a	0.179	n/a	0.193	n/a	0.199	0.205	0.202	0.205
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TH#8	LOX mfd P (psia) [PT0359]	234	203	235	197	274	241	229	208	204	205	200
	LOX mfd T (F) [TT0359]	-245	-260	-244	-255	-237	-238	-247	-260	-258	-260	-260
	Fuel mfd P (psig) [PT0159]	28	229	35	238	8	218	31	207	198	199	195
	Pc (psig) [PT0008]	31	31	33	31	9	16	31	29	32	29	32
	LOX side density (lb_m/ft^3)	61	64.5	61	63	n/a	n/a	62	64.5	64	64.5	64.5
	LOX side flow rate (lb_m/s)	1.43	1.43	1.35	1.40	0.78	0.91	1.38	1.43	1.43	1.40	1.43
	LOX side ACd (in^2)	0.020	0.021	0.019	0.021	n/a	n/a	0.019	0.021	0.021	0.021	0.021
	Fuel side flow rate (lb_m/s)	n/a	0.40	n/a	0.40	n/a	0.39	n/a	0.39	0.40	0.40	0.39
	Fuel side ACd (in^2)	n/a	0.177	n/a	0.170	n/a	0.184	n/a	0.192	0.202	0.200	0.202
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
LOW thrust side ave. Pc(psig)		26	31	31	31	10	15	30	29	30	28	31
LOW thrust side ave. MR		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
LOW thrust side ave. C*, eff. (%)		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

* GHe used on fuel side ** Ignition test *** instrumentation questionable ^LN2/GHe used for LOX/GH2

Table 11. Summary of LASRE engine performance (Continued).

	Test #	GRUN0027*		GRUN0026*		GRUN0025*		GRUN0024*		GRUN0023*		GRUN0022*	
	Test date	12/3/96		11/22/96		11/15/96		11/9/96		10/25/96		10/12/96	
	Test Objective	Gd. cold flow		Gd. cold flow		Gd. cold flow		Gd. cold flow		Gd. cold flow		Gd. cold flow	
	Blow #	1	2	1	2	1	2	1	"2"	1	2	1	2
	HIGH Thrust Side												
TH#1	LOX mfd P (psia) [PT0352]	189	200	186	178	186	181	185	203	197	197	219	216
	LOX mfd T (F) [TT0352]	-256	-240	-254	-260	-253	-258	-254	-242	-249	-251	-243	-242
	Fuel mfd P (psig) [PT0152]	196	3	193	197	198	194	198	195	189	194	197	196
	Fuel mfd T (F) [TT0152]	72	40	75	38	68	62	85	71	61	60	83	65
	Pc (psig) [PT0001]	32	4	33	33	32	33	32	30	31	32	33	33
	LOX side density (lb_m/ft^3)	64	60	63	64.5	63	64	63	60	62	63	60	60
	LOX side flow rate (lb_m/s)	1.38	1.35	1.43	1.43	1.40	1.43	1.35	1.25	1.40	1.40	1.35	1.30
	LOX side ACd (in^2)	0.022	0.019	0.023	0.023	0.022	0.023	0.022	0.019	0.022	0.022	0.020	0.019
	Fuel side flow rate (lb_m/s)	0.38	---	0.38	0.39	0.38	0.39	0.38	0.38	0.37	0.39	0.38	0.38
	Fuel side ACd (in^2)	0.199	---	0.202	0.196	0.198	0.201	0.198	0.197	0.197	0.201	0.197	0.196
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TH#2	LOX mfd P (psia) [PT0353]	192	201	186	182	183	178	189	206	198	190	216	212
	LOX mfd T (F) [TT0353]	-250	-239	-250	-256	-250	-254	-248	-238	-245	-245	-235	-237
	Fuel mfd P (psig) [PT0153]	192	2	184	193	194	190	191	192	184	191	194	193
	Pc (psig) [PT0002]	29	4	30	30	30	30	30	29	28	32	30	30
	LOX side density (lb_m/ft^3)	62	60	62	64	62	63	62	60	61	61	59	59
	LOX side flow rate (lb_m/s)	1.38	1.35	1.43	1.43	1.40	1.43	1.35	1.25	1.40	1.40	1.35	1.30
	LOX side ACd (in^2)	0.021	0.019	0.023	0.023	0.023	0.023	0.021	0.019	0.022	0.022	n/a	n/a
	Fuel side flow rate (lb_m/s)	0.38	---	0.38	0.39	0.38	0.39	0.38	0.38	0.37	0.39	0.38	0.38
	Fuel side ACd (in^2)	0.203	---	0.211	0.200	0.201	0.205	0.205	0.200	0.201	0.204	0.200	0.199
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TH#3	LOX mfd P (psia) [PT0354]	189	205	189	185	196	185	195	212	200	201	220	219
	LOX mfd T (F) [TT0354]	-251	-242	-251	-256	-252	-249	-250	-241	-248	-250	-241	-242
	Fuel mfd P (psig) [PT0154]	185	3	184	184	190	188	191	186	180	186	191	190
	Pc (psig) [PT0003]	29	1	30	30	31	29	31	32	28	28	31	31
	LOX side density (lb_m/ft^3)	63	60	63	64	63	62	62	60	62	62	60	61
	LOX side flow rate (lb_m/s)	1.38	1.35	1.43	1.43	1.40	1.43	1.35	1.25	1.40	1.40	1.35	1.30
	LOX side ACd (in^2)	0.022	0.019	0.022	0.023	0.022	0.023	0.021	0.019	0.021	0.021	0.020	0.019
	Fuel side flow rate (lb_m/s)	0.38	---	0.38	0.39	0.38	0.39	0.38	0.38	0.37	0.39	0.38	0.38
	Fuel side ACd (in^2)	0.210	---	0.211	0.209	0.205	0.207	0.205	0.206	0.206	0.209	0.203	0.201
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TH#4	LOX mfd P (psia) [PT0355]	198	207	192	182	195	187	192	212	203	204	223	221
	LOX mfd T (F) [TT0355]	-246	-240	-249	-250	-247	-251	-246	-234	-245	-247	-233	-235
	Fuel mfd P (psig) [PT0155]	196	5	195	198	197	195	194	195	187	194	199	196
	Pc (psig) [PT0004]	30	0	30	31	29	29	30	29	30	30	31	31
	LOX side density (lb_m/ft^3)	61	60	62	62	62	63	61	59	61	62	58	59
	LOX side flow rate (lb_m/s)	1.38	1.35	1.43	1.43	1.40	1.43	1.35	1.25	1.40	1.40	1.35	1.30
	LOX side ACd (in^2)	0.021	0.019	0.022	0.023	0.022	0.022	0.021	n/a	0.021	0.021	n/a	n/a
	Fuel side flow rate (lb_m/s)	0.38	---	0.38	0.39	0.38	0.39	0.38	0.38	0.37	0.39	0.38	0.38
	Fuel side ACd (in^2)	0.199	---	0.200	0.196	0.199	0.200	0.202	0.197	0.198	0.201	0.198	0.196
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
HIGH thrust side ave. Pc (psig)		30	2	31	31	31	30	31	30	29	31	31	31
HIGH thrust side ave. MR		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
HIGH thrust side ave. C*, eff. (%)		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

* GHe used on fuel side   ** Ignition test   *** instrumentation questionable   ^LN2/GHe used for LOX/GH2

Table 11. Summary of LASRE engine performance (Continued).

	Test #	GRUN0027*		GRUN0026*		GRUN0025*		GRUN0024*		GRUN0023*		GRUN0022*	
	Test date	12/3/96		11/22/96		11/15/96		11/9/96		10/25/96		10/12/96	
	Test Objective	Gd. cold flow		Gd. cold flow		Gd. cold flow		Gd. cold flow		Gd. cold flow		Gd. cold flow	
	Blow #	1	2	1	2	1	2	1	"2"	1	2	1	2
	LOW Thrust Side												
TH#5	LOX mfd P (psia) [PT0356]	193	192	196	190	195	192	190	209	209	207	220	222
	Fuel mfd P (psig) [PT0156]	204	6	201	207	200	202	207	210	196	200	208	203
	Fuel mfd T (F) [TT0156]	90	56	95	51	82	79	98	85	75	75	100	80
	Pc (psig) [PT0005]	32	1	32	30	30	29	32	34	31	32	32	32
	LOX side density (lb_m/ft^3)	62	61	62	63	62	63	61	59	61	61	59	59
	LOX side flow rate (lb_m/s)	1.40	1.33	1.40	1.38	1.40	1.43	1.35	1.28	1.40	1.40	1.33	1.35
	LOX side ACd (in^2)	0.022	0.019	0.022	0.022	0.022	0.022	0.022	n/a	0.021	0.021	n/a	n/a
	Fuel side flow rate (lb_m/s)	0.37	---	0.37	0.38	0.38	0.38	0.38	0.38	0.37	0.39	0.40	0.40
	Fuel side ACd (in^2)	0.191	---	0.192	0.185	0.195	0.194	0.191	0.186	0.191	0.198	0.200	0.202
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TH#6	LOX mfd P (psia) [PT0357]	190	194	192	190	185	186	193	205	205	203	217	218
	LOX mfd T (F) [TT0357]	-247	-243	-247	-252	-249	-251	-246	-236	-244	-246	-237	-237
	Fuel mfd P (psig) [PT0157]	190	5	194	197	201	193	196	197	189	193	197	197
	Pc (psig) [PT0006]	28	0	29	31	27	28	31	30	27	27	29	29
	LOX side density (lb_m/ft^3)	62	61	62	63	62	63	61	59	61	61	59	59
	LOX side flow rate (lb_m/s)	1.40	1.33	1.40	1.38	1.40	1.43	1.35	1.28	1.40	1.40	1.33	1.35
	LOX side ACd (in^2)	0.022	0.019	0.022	0.022	0.022	0.022	0.021	n/a	0.021	0.021	n/a	n/a
	Fuel side flow rate (lb_m/s)	0.37	---	0.37	0.38	0.38	0.38	0.38	0.38	0.37	0.39	0.40	0.40
	Fuel side ACd (in^2)	0.204	---	0.199	0.194	0.194	0.202	0.201	0.198	0.198	0.205	0.211	0.208
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TH#7	LOX mfd P (psia) [PT0358]	187	188	181	179	182	179	189	205	199	198	215	213
	Fuel mfd P (psig) [PT0158]	190	1	194	191	192	194	195	191	184	191	192	194
	Pc (psig) [PT0007]	31	2	31	28	29	28	31	29	31	31	30	30
	LOX side density (lb_m/ft^3)	61	61	61	63	62	63	61	59	61	61	59	59
	LOX side flow rate (lb_m/s)	1.40	1.33	1.40	1.38	1.40	1.43	1.35	1.28	1.40	1.40	1.33	1.35
	LOX side ACd (in^2)	0.023	0.019	0.023	0.022	0.023	0.023	0.022	n/a	0.022	0.022	n/a	n/a
	Fuel side flow rate (lb_m/s)	0.37	---	0.37	0.38	0.38	0.38	0.38	0.38	0.37	0.39	0.40	0.40
	Fuel side ACd (in^2)	0.204	---	0.199	0.199	0.203	0.201	0.201	0.204	0.202	0.207	0.216	0.211
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TH#8	LOX mfd P (psia) [PT0359]	190	196	193	193	185	187	193	210	209	206	223	221
	LOX mfd T (F) [TT0359]	-245	-244	-246	-252	-247	-251	-243	-234	-242	-245	-234	-237
	Fuel mfd P (psig) [PT0159]	197	4	194	202	202	199	198	197	188	202	198	199
	Pc (psig) [PT0008]	31	2	31	32	30	30	33	34	31	33	34	33
	LOX side density (lb_m/ft^3)	61	61	61	63	62	63	61	59	61	61	59	59
	LOX side flow rate (lb_m/s)	1.40	1.33	1.40	1.38	1.40	1.43	1.35	1.28	1.40	1.40	1.33	1.35
	LOX side ACd (in^2)	0.022	0.019	0.022	0.021	0.022	0.023	0.021	n/a	0.021	0.021	n/a	n/a
	Fuel side flow rate (lb_m/s)	0.37	---	0.37	0.38	0.38	0.38	0.38	0.38	0.37	0.39	0.40	0.40
	Fuel side ACd (in^2)	0.197	---	0.199	0.189	0.193	0.197	0.199	0.198	0.199	0.196	0.210	0.206
	MR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
LOW thrust side ave. Pc (psig)		31	1	31	30	29	29	32	32	30	31	31	31
LOW thrust side ave. MR		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
LOW thrust side ave. C*, eff. (%)		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

* GHe used on fuel side ** Ignition test *** instrumentation questionable ^LN2/GHe used for LOX/GH2

Table 11. Summary of LASRE engine performance (Continued).

Test #		GRUN0020*		GRUN0019*	
Test date		9/1/96		7/26/96	
Test Objective		Gd. cold flow		Gd. cold flow	
Blow #		1	2	1	2
HIGH Thrust Side					
TH#1	LOX mfd P (psia) [PT0352]	185	---	206	178
	LOX mfd T (F) [TT0352]	-254	---	-250	-259
	Fuel mfd P (psig) [PT0152]	101	---	194	192
	Fuel mfd T (F) [TT0152]	n/a	---	102	83
	Pc (psig) [PT0001]	21	---	35	36
	LOX side density (lb_m/ft^3)	63	---	62	64
	LOX side flow rate (lb_m/s)	1.40	---	1.45	1.40
	LOX side ACd (in^2)	0.022	---	0.022	0.023
	Fuel side flow rate (lb_m/s)	0.21	---	0.37	0.38
	Fuel side ACd (in^2)	n/a	---	0.201	0.204
	MR	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a
TH#2	LOX mfd P (psia) [PT0353]	188	---	200	181
	LOX mfd T (F) [TT0353]	-250	---	-282***	-284***
	Fuel mfd P (psig) [PT0153]	97	---	183	182
	Pc (psig) [PT0002]	15	---	28	29
	LOX side density (lb_m/ft^3)	62	---	69	69
	LOX side flow rate (lb_m/s)	1.40	---	1.45	1.40
	LOX side ACd (in^2)	0.021	---	n/a	n/a
	Fuel side flow rate (lb_m/s)	0.21	---	0.37	0.38
	Fuel side ACd (in^2)	n/a	---	0.212	0.215
	MR	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a
TH#3	LOX mfd P (psia) [PT0354]	190	---	205	185
	LOX mfd T (F) [TT0354]	-255	---	-282	-289***
	Fuel mfd P (psig) [PT0154]	87	---	190	193
	Pc (psig) [PT0003]	17	---	31	31
	LOX side density (lb_m/ft^3)	63	---	69	70
	LOX side flow rate (lb_m/s)	1.40	---	1.45	1.40
	LOX side ACd (in^2)	0.021	---	0.021	n/a
	Fuel side flow rate (lb_m/s)	0.21	---	0.37	0.38
	Fuel side ACd (in^2)	n/a	---	0.205	0.203
	MR	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a
TH#4	LOX mfd P (psia) [PT0355]	163***	---	173***	154***
	LOX mfd T (F) [TT0355]	-247	---	-266	-273
	Fuel mfd P (psig) [PT0155]	98	---	194	194
	Pc (psig) [PT0004]	18	---	33	28
	LOX side density (lb_m/ft^3)	62	---	66	67
	LOX side flow rate (lb_m/s)	1.40	---	1.45	1.40
	LOX side ACd (in^2)	n/a	---	n/a	n/a
	Fuel side flow rate (lb_m/s)	0.21	---	0.37	0.38
	Fuel side ACd (in^2)	n/a	---	0.201	0.202
	MR	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a
HIGH thrust side ave. Pc (psig)		18	--	32	31
HIGH thrust side ave. MR		n/a	n/a	n/a	n/a
HIGH thrust side ave. C*, eff. (%)		n/a	n/a	n/a	n/a

* GHe used on fuel side ** Ignition test *** instrumentation questionable ^LN2/GHe used for LOX/GH2

Table 11. Summary of LASRE engine performance (Continued).

	Test #	GRUN0020*		GRUN0019*	
	Test date	9/1/96		7/26/96	
	Test Objective	Gd. cold flow		Gd. cold flow	
	Blow #	1	2	1	2
	LOW Thrust Side				
TH#5	LOX mfd P (psia) [PT0356]	193	---	202	191
	Fuel mfd P (psig) [PT0156]	115	---	249***	251***
	Fuel mfd T (F) [TT0156]	n/a	---	110	86
	Pc (psig) [PT0005]	14	---	31	27
	LOX side density (lb_m/ft^3)	61	---	66	68
	LOX side flow rate (lb_m/s)	1.38	---	1.43	1.43
	LOX side ACd (in^2)	0.021	---	0.021	0.021
	Fuel side flow rate (lb_m/s)	0.21	---	0.38	0.38
	Fuel side ACd (in^2)	n/a	---	n/a	n/a
	MR	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a
TH#6	LOX mfd P (psia) [PT0357]	194	---	204	182
	LOX mfd T (F) [TT0357]	-245	---	-269	-276
	Fuel mfd P (psig) [PT0157]	96	---	191	193
	Pc (psig) [PT0006]	10	---	30	30
	LOX side density (lb_m/ft^3)	61	---	66	68
	LOX side flow rate (lb_m/s)	1.38	---	1.43	1.43
	LOX side ACd (in^2)	0.020	---	0.021	0.022
	Fuel side flow rate (lb_m/s)	0.21	---	0.38	0.38
	Fuel side ACd (in^2)	n/a	---	0.210	0.205
	MR	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a
TH#7	LOX mfd P (psia) [PT0358]	188	---	196	179
	Fuel mfd P (psig) [PT0158]	88	---	190	190
	Pc (psig) [PT0007]	16	---	31	30
	LOX side density (lb_m/ft^3)	61	---	64	68
	LOX side flow rate (lb_m/s)	1.38	---	1.43	1.43
	LOX side ACd (in^2)	0.021	---	0.022	0.022
	Fuel side flow rate (lb_m/s)	0.21	---	0.38	0.38
	Fuel side ACd (in^2)	n/a	---	0.211	0.208
	MR	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a
TH#8	LOX mfd P (psia) [PT0359]	191	---	204	188
	LOX mfd T (F) [TT0359]	-245	---	-259	-276
	Fuel mfd P (psig) [PT0159]	99	---	192	195
	Pc (psig) [PT0008]	17	---	34	33
	LOX side density (lb_m/ft^3)	61	---	64	68
	LOX side flow rate (lb_m/s)	1.38	---	1.43	1.43
	LOX side ACd (in^2)	0.021	---	0.021	0.022
	Fuel side flow rate (lb_m/s)	0.21	---	0.38	0.38
	Fuel side ACd (in^2)	n/a	---	0.209	0.203
	MR	n/a	n/a	n/a	n/a
	actual C* (ft/s)	n/a	n/a	n/a	n/a
	C*, efficiency (%)	n/a	n/a	n/a	n/a
LOW thrust side ave. Pc (psig)		14	--	32	30
LOW thrust side ave. MR		n/a	n/a	n/a	n/a
LOW thrust side ave. C*, eff. (%)		n/a	n/a	n/a	n/a

* GHe used on fuel side ** Ignition test *** instrumentation questionable ^LN2/GHe used for LOX/GH2

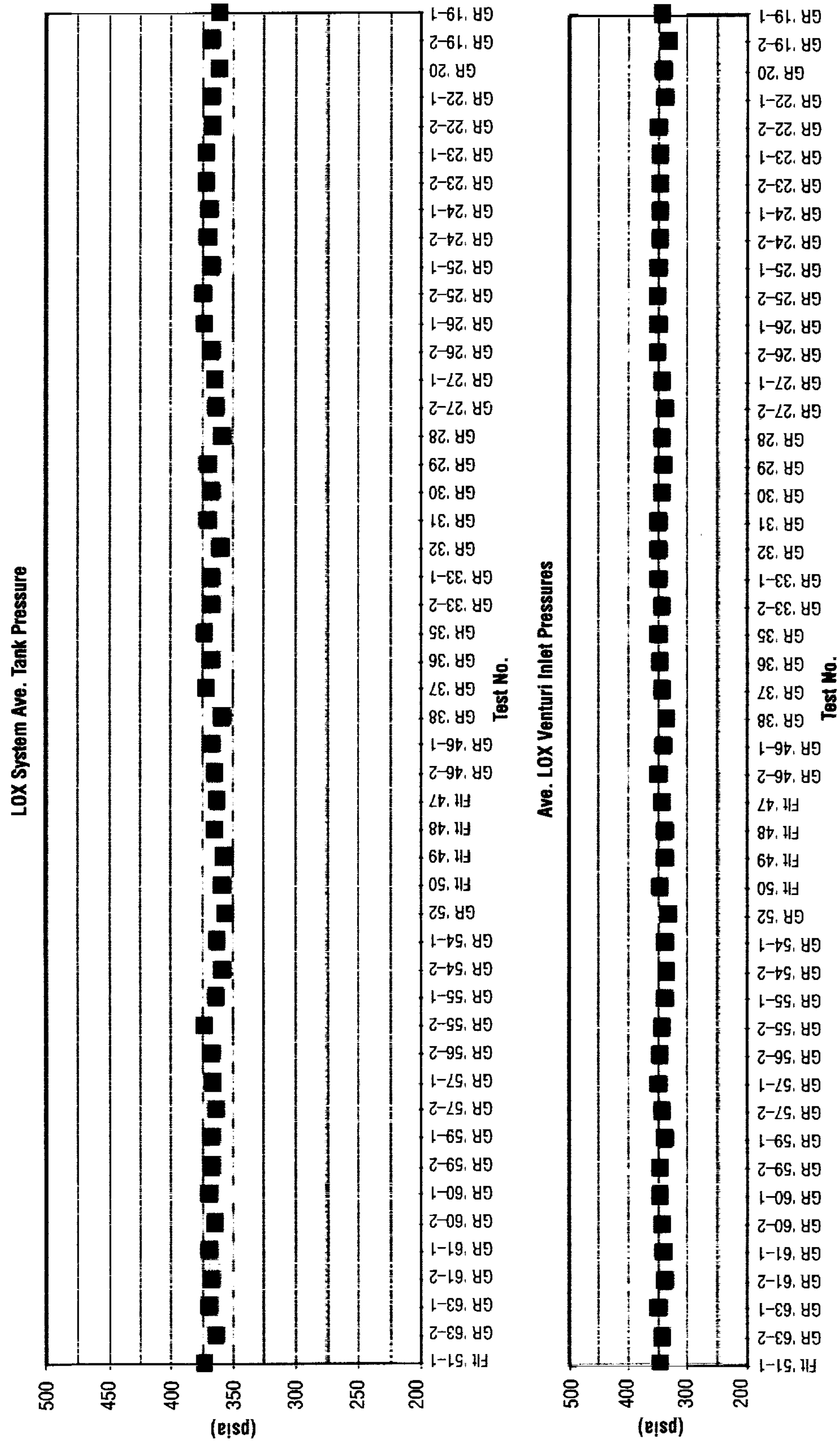


Figure 17. Steady-state trends in the LOX system data.

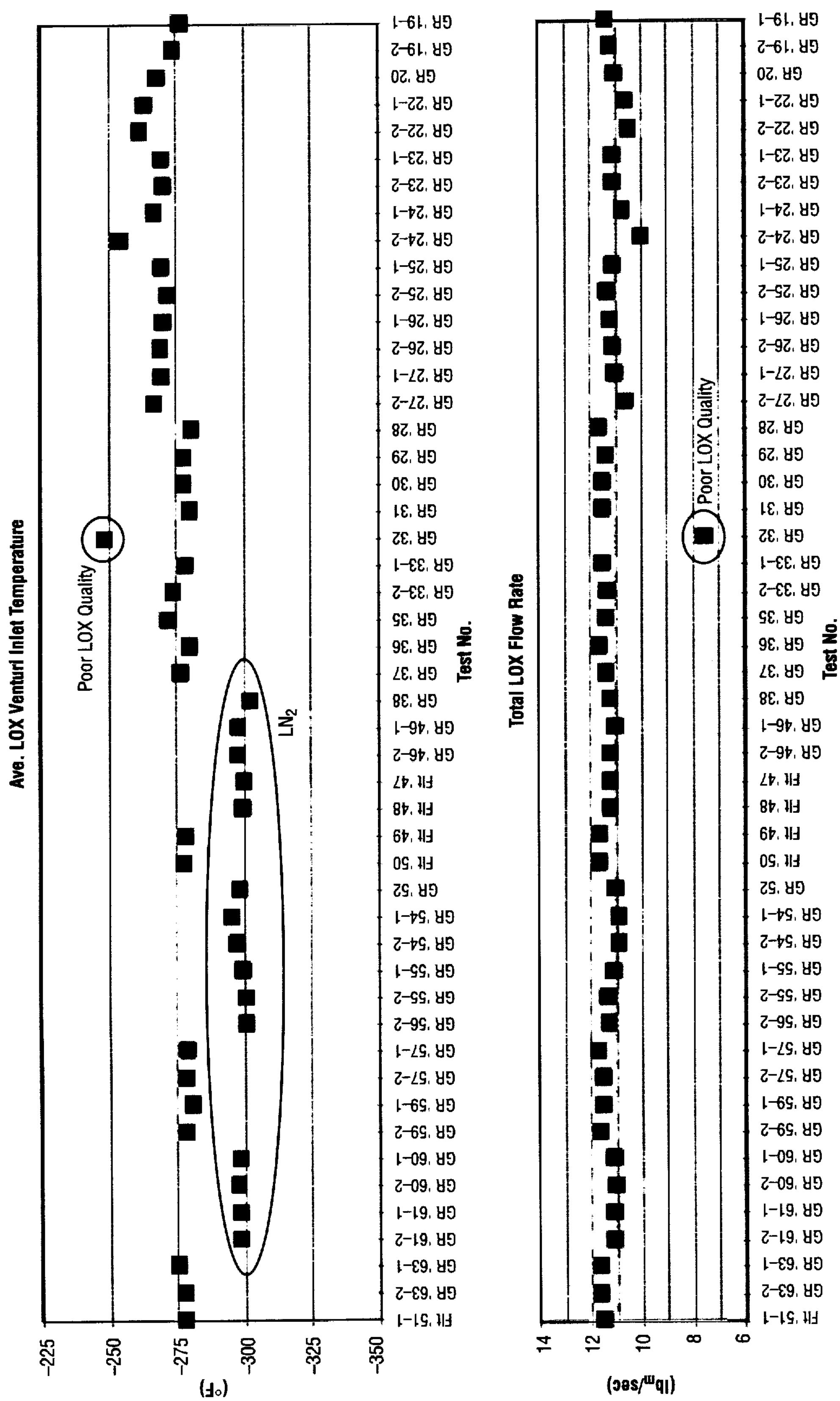


Figure 17. Steady-state trends in the LOX system data (Continued).

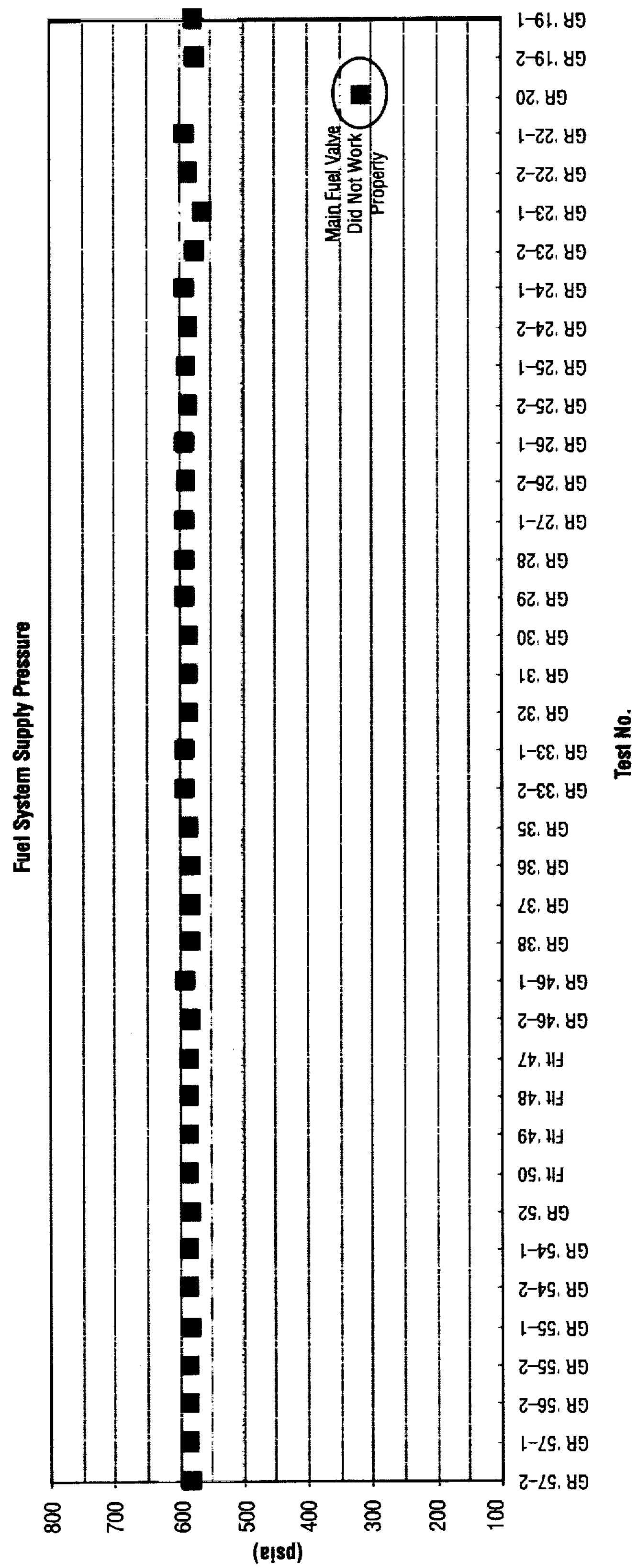


Figure 18. Steady-state trends in the fuel system data.

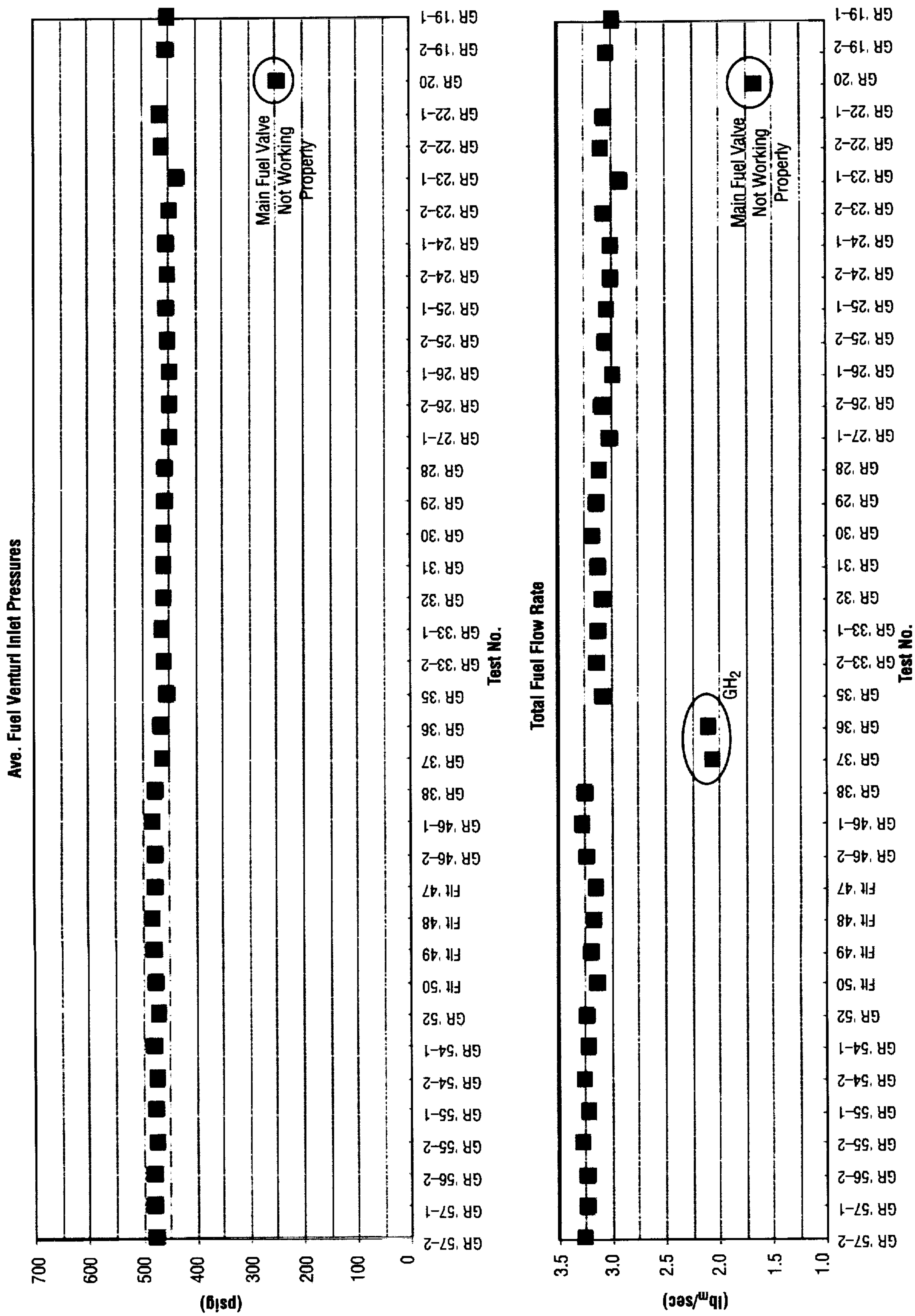


Figure 18. Steady-state trends in the fuel system data (Continued).

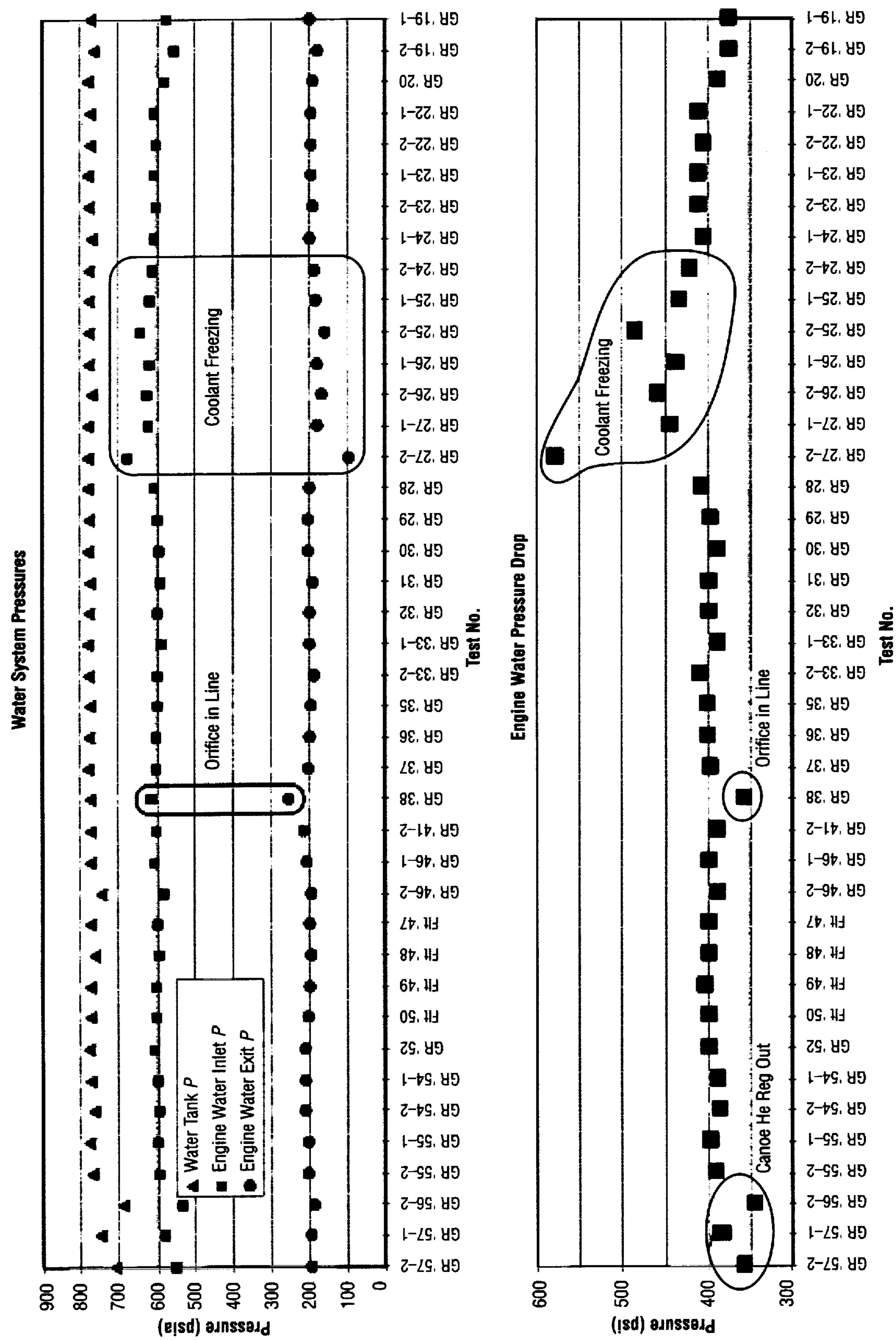


Figure 19. Steady-state trends in the water system data.

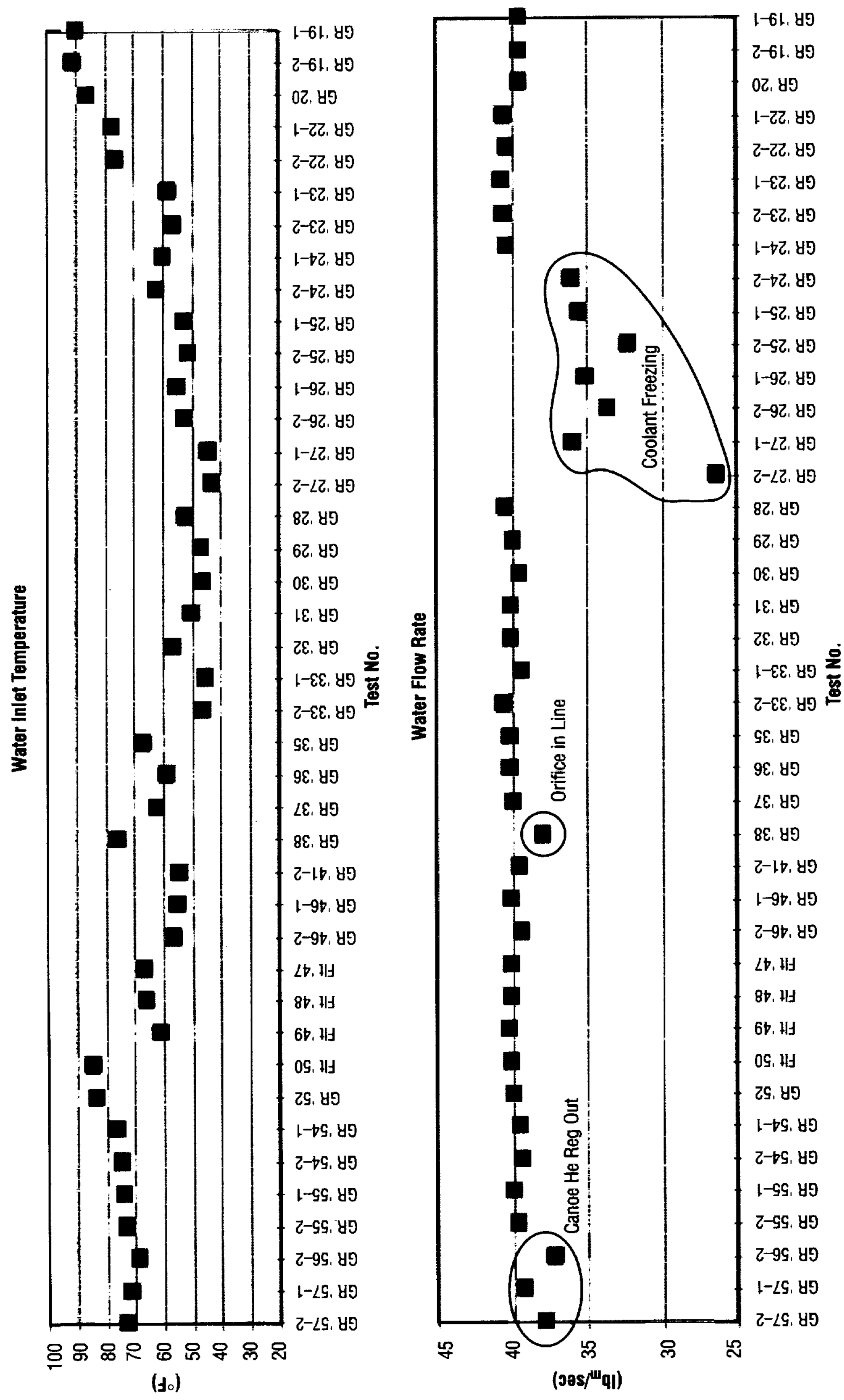


Figure 19. Steady-state trends in the water system data (Continued).

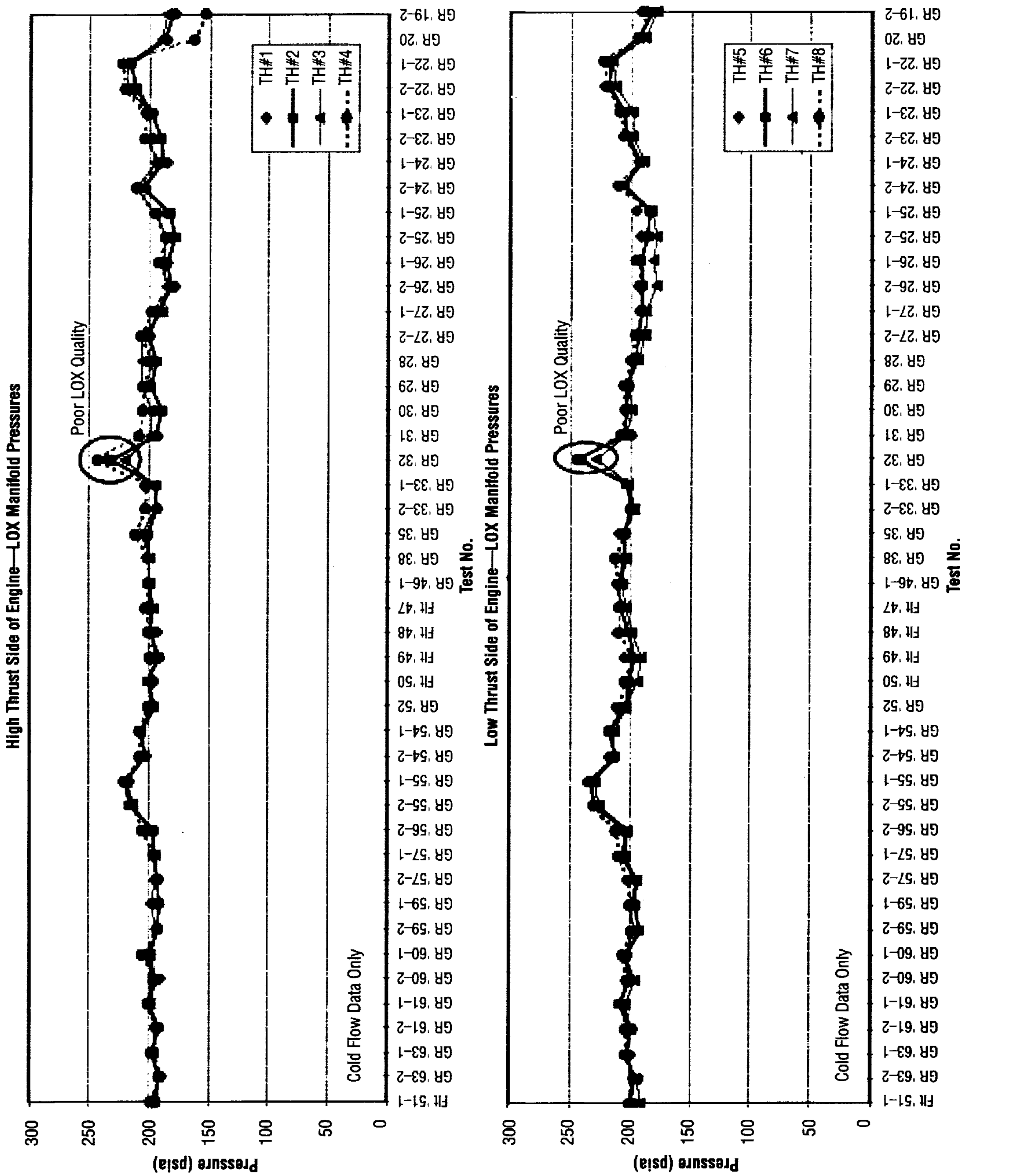


Figure 20. Steady-state trends in the thruster data.

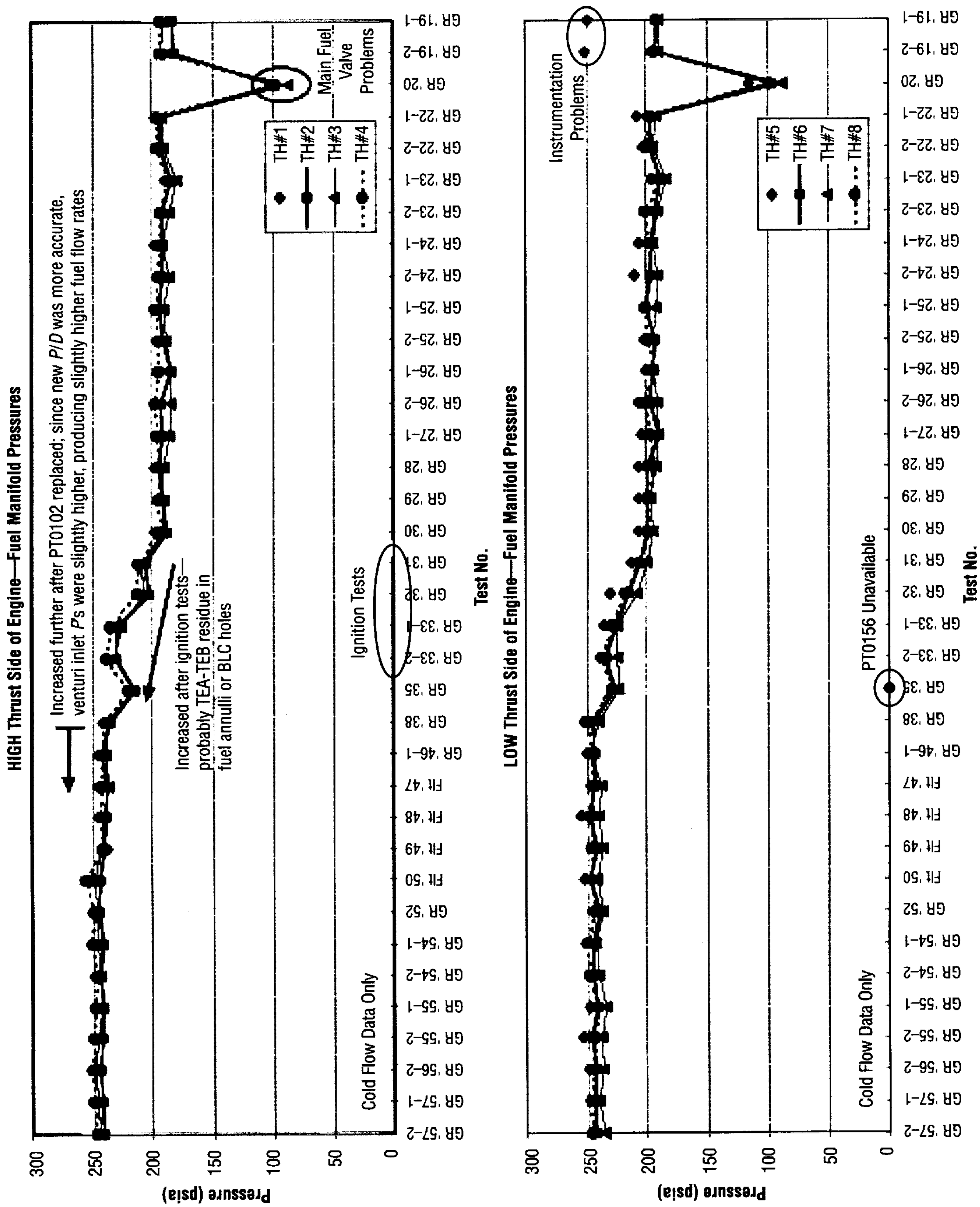


Figure 20. Steady-state trends in the thruster data (Continued).

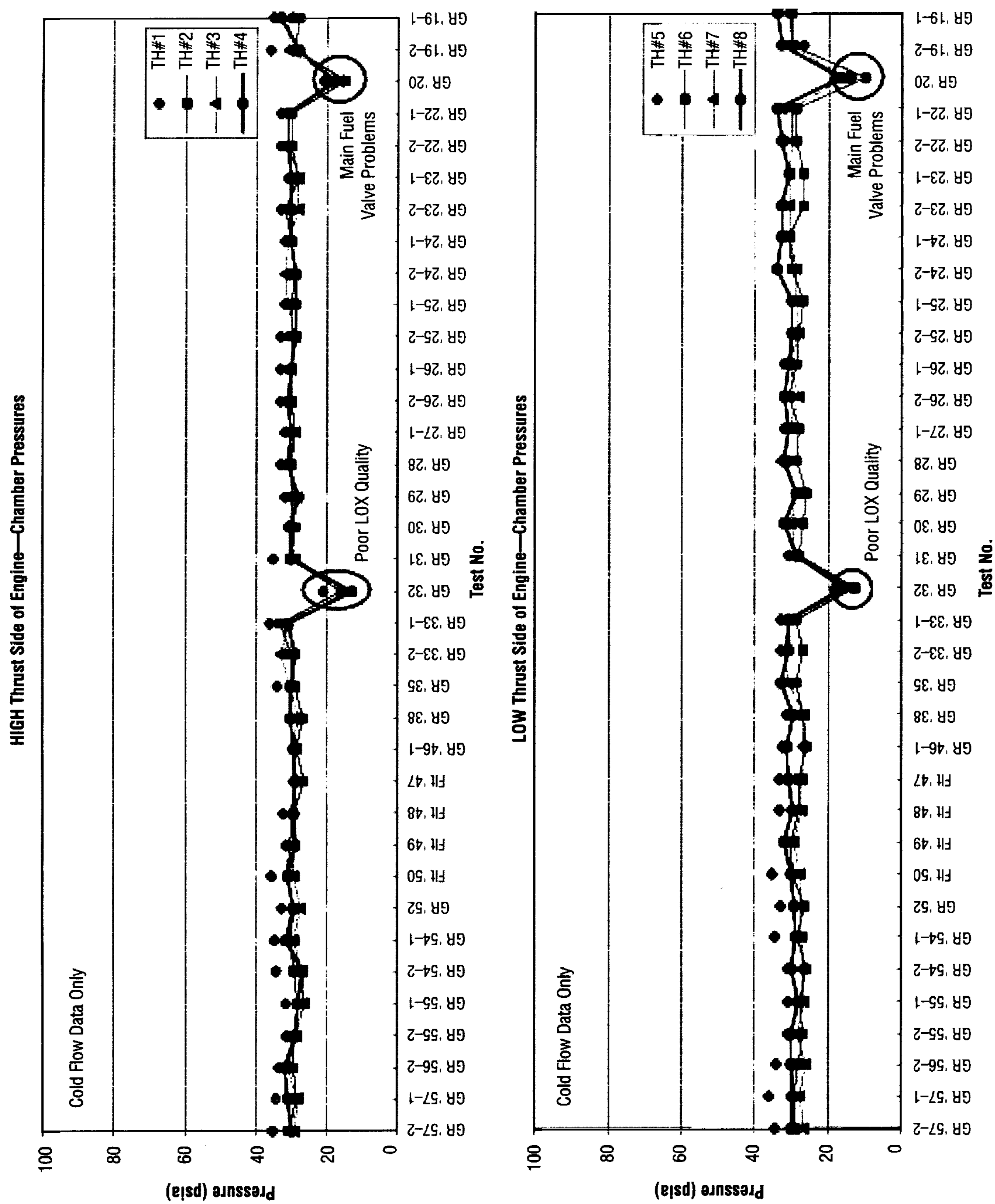


Figure 20. Steady-state trends in the thruster data (Continued).

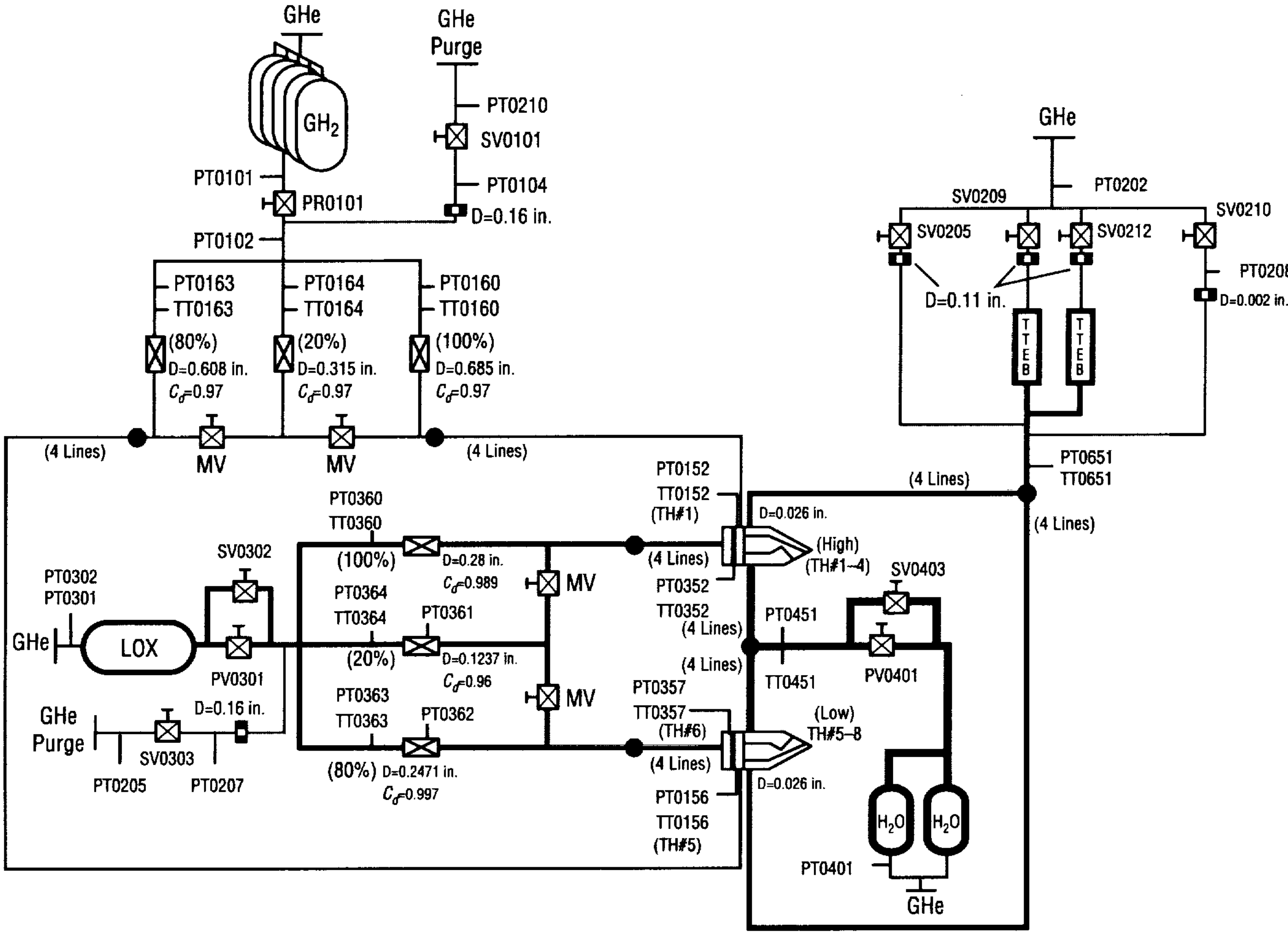


Figure 21. LASRE engine supply systems.

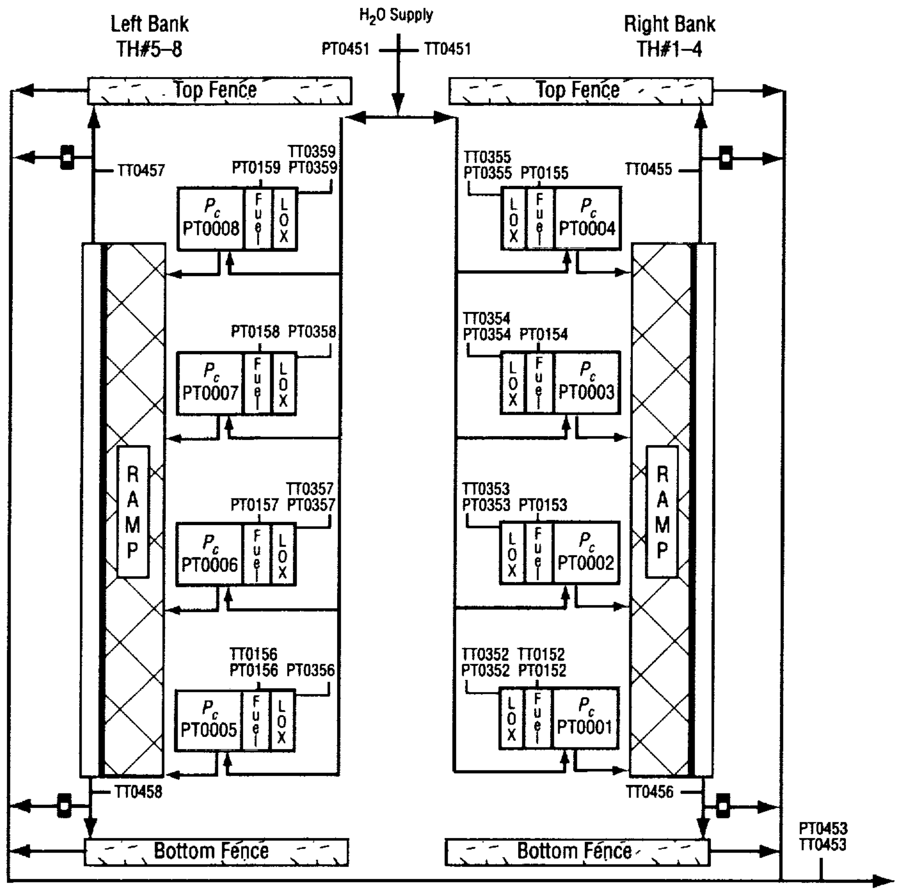


Figure 22. LASRE engine thrusters and water system.

Table 12. Additional notes for GRUN0019–GRUN0063 tests.

Test #	Notes
GRUN0019 7/26/96 Gd. cold flow	TTEB #2 did not provide flow in 2nd blow LOX T/C's were checked & corrections had to be applied to all T/C data PT0355 reading low (TH#4), PT0156 reading high (TH#5) LOX leaked between blows
GRUN0020 9/1/96 Gd. cold flow	Main fuel valve did not work properly in 1st blow - provided low pressure to venturies LOX leaked between blows 2nd blow aborted in PS, since inadequate ΔT was measured for LOX system (LOX system remained cold due to leak) Main fuel valve did not work properly in autosafe (a/s) either & produced high enough pressure to rupture burst disc
GRUN0022 10/12/96 Gd. cold flow	Aborted in PS 3 times-exceeded water tank R/L (proceeded after raising R/L value) PT0360 inop LOX prechill line disconnected from engine - flow dumped overboard & showed that valve closed slowly Engine water froze during LOX a/s Leaks found in engine water fittings
GRUN0023 10/25/96 Gd. cold flow	Main fuel valve started closing early near end of each blow & fuel a/s aborted as valve closed early Water a/s (added to sequence prior to LOX a/s) attempted - performed twice to remove all water LOX a/s aborted - low He pressure (PT0651) LOX prechill line still disconnected from engine Water system F/M removed (to prevent overspinning in water a/s)
GRUN0024 11/9/96 Gd. cold flow	1st blow successful, 2nd blow aborted due to high controller temp. Later attempted another test, providing 3rd blow successfully (data shown for "2" on summary sheets) Aborted in a/s (high controller temp. again) New LOX prechill valve closed properly - no apparent leaks
GRUN0025 11/15/96 Gd. cold flow	Aborted in 2nd blow when fuel system burst disc ruptured (providing low fuel system pressure). No high pressure observed, but burst disc ruptured anyway Water frozen at start of 2nd blow (higher ΔP due to higher line R) & possibly during 1st blow Fuel mfd. temps still reading "off" Revised water a/s still didn't remove all water
GRUN0026 11/22/96 Gd. cold flow	No aborts Water frozen at start of 2nd blow & possibly during 1st blow Fuel mfd. temps still reading "off" Possible small water & LOX leaks observed
GRUN0027 12/3/96 Gd. cold flow	1st blow showed indications of water freezing similar to GRUN0025 & 26 (higher engine inlet P, lower engine outlet P) All water had been confirmed drained from engine prior to test, unlike -25 & -26 when there may have been residual H2O 2nd blow had enough frozen water to increase water tank pressure above R/L, which aborted 2nd blow before fuel flow Fuel a/s performed, but no water or LOX a/s attempted LOX leak observed from area around LOX prechill valve Water B/D (rchk0009) performed on 11/27/96 confirmed line R's and water flow rate with F/M in place - compared well to original water B/D's F/M kept in place for this test to provide flow data relative to frozen flow Fuel mfd temps. still reading "off"
GRUN0028 12/11/96 Gd. cold flow	Only single blow performed (as planned) Sequence changes implemented to reduce water trickle flow during LOX prechill & to move 2nd "start" press after LOX tank is pressurized. (Everything that was performed in PS now occurs in SS, except for pr'ng LOX tank) Also, TC's added to each thruster (outer surfaces - near mold lines) - data recorded by PL Higher water flow rate observed with same engine pressure drop as observed in water b/d LOX leak at tank fitting observed Trapped pressure in main fuel purge line (PT0104) when fuel purge valve (SV0101) cycled to relieve He mfd pressure (SV0101 set to open when PT0210 > 1325 psi)
GRUN0029 12/17/96 Gd. cold flow	Only single blow required Aborted in 1st attempt when water tank HIGH R/L was reached due to spike in water system after valve was opened. After powering controller off/on, 2nd attempt provided full duration (data shown) Water F/M inop - flow rate est. from engine ΔP & result in GRUN0028

Table 12. Additional notes for GRUN0019–GRUN0063 tests (Continued).

Test #	Notes
GRUN0030 1/18/97 Gd. cold flow	Only single blow planned - performed with no aborts Fuel mfd temps. reading "off" again & TT0156 responds to LOX flow with a drop in temp (like in GRUN0027 & others) Water F/M inop - no plans to replace (flow rate est. from engine ΔP) Water valve leaked after blow
GRUN0031 1/23/97 Ignition test	1st ignition test attempt - performed with no aborts (TTEB #1 cartridge used) All 8 thrusters lit to approx. same Pc (~30-35 psig) at the same time Backflow of LOX/TTEB ignition observed in each fuel mfd relative to fuel mfd pressures, also fuel mfd temp. TT0152 reached ~360 F due to ignition backflow Offset between TT0152 and TT0156 still present, but TT0156 did not respond to LOX flow with a drop in temp. like in GRUN0030 Proposed sequence change will check Pc's for ignition detect earlier, so fuel can come on earlier (before all TTEB is expended) Water valve still leaking Post-test inspections showed minimal amount of coating spalled off several of the thrusters (mostly d/s of throat)
GRUN0032 1/31/97 Ignition test	2nd ignition test attempt with following sequence changes implemented prior to test: 0.2 sec delay between signalling fuel valve open and signalling fuel purge valve closed (to aid in removing LOX/TTEB from fuel mfds. before hydrogen reaches injectors) Ignition detect timer started earlier (to allow fuel flow to start & reach injectors before all TTEB is expended) TTEB #2 cartridge used Full tank of LOX not available, so LOX quality was poor throughout test. Warmer LOX temps. created lower flow rates and lower ignition pressures (~10 psig) with TTEB. (With the venturies uncavitated, 80% & 20% flow rates were estimated from the venturi ΔP's, and flow thru the 100% venturi was assumed to be equal to their total.) Fuel mfds. showed evidence of LOX/TTEB backflow - TT0156 reached ~210 F, while TT0152 remained around ambient. Water valve still leaking Possible leaks in fuel purge line suspected - trapped pressure at PT0104 decreases during main fuel flow instead of remaining steady.
GRUN0033 2/6/97 Ignition test	2 ignition tests performed using both TTEB circuits Sequence changes implemented prior to test: Delayed opening of fuel valve to allow LOX/TTEB to burn completely - to determine the exact amount of TTEB available. (Created 2 sec of main flow instead of 3 sec for each blow.) Ignition in 1st blow (cartridge #2): All Pc's rose to same level (30-40 psig) except TH#5, which was much lower (10-15 psig)- indicating blocked port Evidence of LOX/TTEB backflow into fuel mfds. based on fuel mfd P's and TT0152 reached 193 F during ignition Also, fuel side 100% venturi inlet T (TT0160) rose to 94 F at the same time TT0152 rose, suggesting back flow all the way up thru this venturi Approx. 0.5 - 0.6 sec of TTEB flow available based on Pc's Main flow in 1st and 2nd blow: All fuel mfd. P's are reading higher compared to cold flows prior to ignition tests (prior to GRUN0031) Ignition in 2nd blow (cartridge #1): TH#5 Pc more consistent with others (blockage came loose?) TT0152 rose even higher during ignition (360 F) Approx. 0.5 sec of TTEB flow available based on Pc's Water pressure low (possible freezing at start of 2nd blow) Water valve still leaking Fuel side resistances have been increasing (higher fuel mfd. pressures) for each thruster since first ignition test. Current resistances indicate 13-17% decrease in fuel side flow areas. Could be LOX/TTEB residue on fuel side from low fuel side purge - blocking fuel holes &/or fuel film cooling holes. Possible leaks in fuel purge line suspected - same behavior as GR'32 during main fuel flow.
2/12/97	1st planned hot-fire: main H2 valve failed after pre-test servicing of hydrogen (bellows experienced H2 embrittlement crack). No test attempted. Valve redesigned to use a piston instead of bellows.

Table 12. Additional notes for GRUN0019–GRUN0063 tests (Continued).

Test #	Notes
GRUN0035 4/16/97 Gd. cold flow	Cold flow with redesigned H2 valve installed (piston type). GHe used for TTEB and H2 systems. PT0156 temporarily removed from TH#5 fuel mfd. (electronics being used for GH2 tank pressure until H2 compatible diaphragm for tank's Sensotech 'ducer is replaced). Only one blow attempted and performed with no aborts Behavior of PT0104 suggests fuel purge line check valve (CV0101) or main fuel purge valve (SV0101) is leaking. During main fuel flow when SV0101 is closed and trapped purge flow should be checked, PT0104 steadily rises instead of remaining steady or decreasing due to leaks (like in GR'32,33). [Similar behavior in fuel a/s]. Confirmed SV0101 was leaking - changed out prior to GR'36.
GRUN0036 4/23/97 Gd. hot fire	1st hot-fire test; Single burn attempted & performed with no aborts. Objective: Pc ~ 200 psia & MR ~ 6.0 for 3 sec Results: Mainstage duration - 3 sec HIGH thrust side - ave. Pc = 228 psia, MR = 5.7 LOW thrust side - ave. Pc = 216 psia, MR = 5.4 Engine coolant ΔP = 402 psi, ΔT = 63 F Fuel side ACd for each thruster decreased further (approx. 30% total reduction). Some coating spalled from thrusters. For ignition, all thruster showed Pc's of 27-36 psig, except TH#5 showed Pc as low as 21 psig; Ignition detect was set at 15 psig. Note: PT0156 P/D used for fuel tank pressure (instead of PT0101). No data available for TH#5 fuel mfd. pressure. Still evidence of leaks in fuel purge line - PT0104 decreases during main fuel flow (same as GR'32 & 33)
GRUN0037 4/30/97 Gd. hot fire	2nd hot-fire test; Single burn attempted & performed with no aborts. Objective: Pc ~ 200 psia & MR ~ 6.0 for 3 sec Results: Mainstage duration - 3 sec HIGH thrust side - ave. Pc = 227 psia, MR = 5.7 LOW thrust side - ave. Pc = 216 psia, MR = 5.4 Engine coolant ΔP = 398 psi, ΔT = 70 F More coating spalled from thrusters. For ignition, all thrusters showed Pc's of 30-36 psig. Ignition detect remained set at 15 psig. Still evidence of leaks in fuel purge line - PT0104 decreases during main fuel flow (same as GR'32,33,36) Note: PT0156 P/D still used for fuel tank pressure, so no data available for TH#5 fuel mfd. pressure.
GRUN0038 9/24/97 Flt. cold flow (grounded)	1st Flight configuration ground cold flow - LN2/GHe used for LOX/GH2 with pod mounted on stationary A/C. One blow planned and performed with no aborts. 1" orifice mistakenly placed in water exit line - created higher water inlet & exit pressures. (Orifice has been removed from configuration since water blowdown results showed it was limiting coolant flow rate.) Orifice will be removed again before next test. PT0362 inop - flat throughout test. PT0156 available again, since PT0101 was replaced. Fuel venturi inlet pressures and fuel manifold pressures 10-20 psi higher than previous tests with GHe because of new P/D in system for PT0102. The value required for PT0102 is set to provide the desired fuel venturi inlet pressures that provide the correct fuel flow rate. The new P/D for PT0102 probably has a more reliable calibration record than the previous P/D. So, the previous test data for PT0102 is probably less accurate. The higher pressures now resulting at the fuel venturies will produce slightly higher fuel flow rates, which will produce lower MR's in subsequent hot fire tests. The value for PT0102 will not be reset, since effects of higher fuel flow rates will be minimal - should only reduce ave. thruster MR from 5.6 to ~ 5.3. (PT0102 was replaced because old P/D turned out to be H2 incompatible.) Still evidence of leaks in fuel purge line - PT0104 decreases during main fuel flow (same as GR'32,33,36,37)

Table 12. Additional notes for GRUN0019–GRUN0063 tests (Continued).

Test #	Notes
GRUN0039 10/3/97 Flt. cold flow (grounded)	2nd Flight configuration ground cold flow - LN2/GHe used for LOX/GH2 with pod mounted on stationary A/C. Planned to demo EMERSS and CNTR PWR OFF shutdowns. (State table changed to make shutdown sequence due to EMERSS abort the same as normal shutdown - 1.25/1.5 sec delay on LOX/fuel engine purges removed.) Aborted in prestart when LOX tank failed to pressurize properly (only reached ~200 psi instead of 365 psi nominal). Data and post-test checks on LOX system suggest the LOX vent valve was leaking, so the LOX tank could not pressurize during prestart. LOX vent valve will be replaced before next cold flow. Leak also suspected in hydrogen vent line based on behavior of oxygen sensors during manual safing of fuel system. Manual safing performed successfully on fuel and LOX systems - but back pressured hydrogen system burst disk, so it needs to be replaced before next cold flow attempt.
CST0004 10/10/97 CST/taxi	Combined systems test and first taxi test with pod mounted on A/C. Pressurized tanks (He, H2, and LOX) showed no leaks. Significant leaks into pod relative to O2 sensors during taxi. N2 purge proved inadequate for keeping air out of pod.
FLT0045 10/31/97	1st aero flight with pod mounted on A/C. No cold flow performed on engine. Ambient hardware temps. ~ 60-80°F throughout flight. Altitude reached ~ 33,000 ft. Max. Mach no. ~ 1.2
GRUN0041 12/9/97 Flt. cold flow (grounded)	2nd Flight configuration ground cold flow - LN2/GHe used for LOX/GH2 with pod mounted on stationary A/C. Retry of GR'39 - with new LOX vent valve. Planned to demo EMERSS and CNTR PWR OFF shutdowns. Also prior to test - changed out H2 system burst disc, performed O2 sensor checks & calibrations, tried to seal air leaks into pod, leak checked H2 vent system. results: LOX vent valve still did not appear to work properly. 1st attempt - aborted in prestart when LOX tank failed to pressurize, like in GR'39 Prior to 2nd attempt - warmed up engine thinking that LOX vent valve has a thermal problem with cold temps. This blow was successful getting to mainstage, and successfully aborted with EMERSS press. 3rd attempt - aborted in prestart when LOX tank failed to pressurize, like in 1st attempt Fuel purge line leak appeared to be fixed.
FLT0046 12/19/97	2nd aero flight. Due to problems pressurizing LOX tank, no cold flow performed. GN2 purge of pod could not be checked either due to failure of SR-71 LN2 dewar heater prior to take off. Altitude reached ~ 50,000 ft. Max. Mach no. ~ 1.6
GRUN0046 2/12/98 Flt. cold flow (grounded)	3rd flight configuration ground cold flow - LN2/GHe used for LOX/GH2 with pod mounted on stationary A/C. Retry of GR'41 after working on LOX vent valve (moved valve orifice downstream from original upstream location to see if that helps solve the LOX vent valve problem). 2 blows planned - planned to demo CNTR PWR OFF shutdown in second blow results: 1st blow - nom. performance; TT0352 inop (also, TT0363 - 20% venturi - staying colder at c/o than other venturies) 2nd blow - water system pressures slower coming up; CNTR PWR OFF initiated 1 sec into main flow LOX & fuel engine supply valves close appropriately to isolate engine; LOX trickle valve slow closing - LOX venturi & mfd pressures drop to same level as trickle flow for ~ 1.5 sec after cntr pwr off; water supply valve remained in active open position, so all water was drained out prior to water a/s; fuel a/s nominal; 2 LOX a/s had to be performed - when controller was powered back on (to perform a/s), LOX tank had to be repressurized - took longer than normal because of larger ullage in LOX tank - 1st a/s timed out before a/s could be completed, so 2nd performed to remove remaining LOX. end of test showed high spike in engine's water inlet pressure (water exit pressure unaffected) - possible due to local droplets on pressure transducer freezing after 2 LOX a/s procedures. All water confirmed drained after test (inspections noted all hdw extremely cold after 2 LOX autosafes.) Water system leak checked to insure integrity.

Table 12. Additional notes for GRUN0019–GRUN0063 tests (Continued).

Test #	Notes
FLT0047 3/4/98 Flt. cold flow	1st in-flight cold flow. LN2/GHe used for LOX/GH2. Cold flow performed at 41,000 ft and M=1.2 Unable to pressurize LOX tank in 1st prestart - same LOX vent valve problem suspected. 2nd prestart LOX tank pressurized to nominal value. Aborted in fuel autosafe - TTEB max pressure redline reached. 2nd fuel autosafe performed for full duration. In previous cold flows - PT0651 also close to hitting R/L of 30 psi. Tripped R/L in this test when PT0651 read ~ 31 psi for 2 consecutive time slices. Increasing R/L to 35 psi to avoid cutoffs in further tests. TT0352 still inop GN2 purge of pod proved inadequate for keeping air out. Pod filled with air shortly after takeoff. Will make further attempts at sealing pod and try another cold flow flight. All other engine & supply system parameters appeared to perform nominally compared to prior cold flows. To adjust gage pressures to absolute pressures, P_{atm} ~ 3 psi at 41,000 ft. (from altitude refs.) (all psia 'ducers read 0-5 psia with no flow, so an average P_{atm} of ~ 3 psia seemed reasonable & was used to convert the psig data) (PT0354, TH#3 LOX mfd P, reads psig. It's initial reading was ~ -11 psig, so it was showing an offset. This pressure was adjusted by adding 11 psig to its steady state measurements and then increased by 3 more psi to convert to psia. PT0358, TH#7 LOX mfd P - which also reads psig, was initially reading ~ -3 psig, so its offset was not as great. It was among the same range as the other LOX mfd P's after adjusting to psia by adding 3 psi.)
FLT0048 3/19/98 Flt. cold flow	2nd in-flight cold flow. LN2/GHe used for LOX/GH2. Cold flow performed at 31,000 ft and M=0.9 Similar to FLT'47 - required 2 prestarts to properly pressurize LOX tank to nominal level. GN2 purge of pod saw some improvement (7-10% O2 levels vs 15% in FLT'47). Will continue attempts to seal the pod even better. All engine & supply system parameters appeared to perform nominally. TT0352 still inop P_{atm} ~ 4 psi at 31-33,000 ft. (PT0354 adjusted with +10 psi again, like in FLT0047) All/most psig 'ducers reading lower with no flow (~-10 psig) compared to ground tests (~0 psig). Possible suction at the back of the engine during flights is creating lower reading on gage pressures when no flow is present.(?)
FLT0049 4/15/98 Flt. cold flow	Flight cold flow w/ignition test planned. LOX/TTEB loaded, GHe used for GH2. Performed at 26,000 ft and M=0.75 No ignition because TTEB was mistakenly loaded into wrong canister. Cold flow state table used, so main cold flow was still performed successfully with LOX and GHe. 2 prestarts req'd again to pressurize LOX tank. GN2 purge of pod improved significantly (3-3.5% O2 levels; 4% is R/L level) LOX leak observed after cold flow completed - O2 sensors > 20% in model after main flow. LOX a/s not performed - manual safe of both LOX and fuel systems performed (fuel manual safe had been planned) Water frozen during water a/s - no pressure reading from PT0453 (engine exit pressure) to indicate flow, and PT0451 (inlet) registered high reading even during water trickle flow, preceding main water flow. Water exit temp (TT0453) and ramp temp TT0455 registered close to freezing temp. of water. All temps cooler to start with compared to other flight tests. No water freezing problems during a/s in FLT'48 & '47, maybe occurred in this test because of LOX leak or because the successful GN2 purge of pod is creating cooler environment around engine. (?) TT0352 still inop P_{atm} ~ 4 psi assumed at 26,000 ft. (PT0354 adjusted again with + 10 psi, like in FLT'48,'47) All engine & supply system parameters appeared to perform nominally. LOX venturi & mfd pressures ~ 20 psi lower during LOX trickle flow compared to FLT'48 & '47. During main flow pressures are at levels similar to FLT'48 & '47. Could imply that LOX leak is in LOX trickle flow line. Post-test: actual LOX leak discovered at check valve (CV0302) in LOX purge line. Seal replaced to fix leak (will also visually verify leak tight w/high pressure LN2 blowdown)
GRUN0047 4/29/98 leak check	Ground test to check for LOX system leaks using LN2 during LOX autosafe. 3 LOX autosafe performed. The LOX vent valve was set to the open position using the cockpit switch for the 1st attempt, and the tank still pressurized. The vent valve was closed for subsequent 2 autosafes. Leak was discovered in the LOX pre-chill line where it connects to the main flow line.

Table 12. Additional notes for GRUN0019–GRUN0063 tests (Continued).

Test #	Notes
GRUN0048 5/5/98 leak check	Ground test to check for LOX system leaks using LN2 during LOX autosafe. 2 LOX autosafes performed. Both LOX tank pressurizations were successful on the first attempt. No leaks observed in LOX system.
GRUN0049 6/12/98 leak check	Ground test to check for LOX system leaks using LN2 during LOX autosafe. All fitting torques were checked prior to test. 2 LOX autosafes performed. Leak observed in LOX purge line at check valve CV0302's fitting.
GRUN0050 6/24/98 leak check	Ground test to check for LOX system leaks using LN2 during LOX autosafe. Fittings at CV0302 were welded to eliminate leak paths prior to test. Four autosafe blow downs were performed with LN2 and no visual leaks were observed. No main flow attempted - only "LOX" autosafes. The system was allowed to warm up to 0 deg F between blows to obtain 4 cryogenic cycles on the system.
FLT0050 7/23/98 Flt. cold flow	Flight cold flow with LOX/GHe to verify LOX system remains leak free in flight with 02 sensors available. Performed at 31,000 ft and M = 0.9 P_{atm} ~ 4 psi (PT0354 adjusted again with +10 psi) Pod sealed even better than last flight - all sensors > 3% Unfortunately, another LOX leak detected after main flow began - 2 sensors shot up 5 sec after blow (sensors 11 & 12 are near top of model). Did not conduct autosafe because of LOX leak. PT0363 read ~ 20 psi higher than PT0360 & PT0364 (venturi inlet pressures) during main flow and ~ 10 psi higher during trickle flow. Fuel mfd pressures on the HIGH thrust side (PT0152-5) read ~ 10 psi higher than FLT'49. Water did not appear frozen during water a/s like it did in FLT'49. Water a/s appeared normal. PT0001 reading slightly higher than PT0002-4, which is not consistent with FLT'49; PT0005 reads slightly higher than PT0006-8 but behavior is consistent with FLT'49.
GRUN0052 7/30/98 Flt. cold flow (grounded)	Ground cold flow with 3% GH2/97% GHe mixture for fuel system leak check. Hydrogen detectors showed no indication of hydrogen leak throughout system during main flow or fuel autosafe. No internal pod GN2 purges were running during the test, so hydrogen could be detected in "unpurged" environment. LOX tank not holding pressure during main flow. SV0304 is supposed to keep PT0301 between 365 & 375 psi, but tank pressures start to drop below 365 psi midway thru the main flow. LOX venturi pressures drop correspondingly. PT0205 (u/s of tank) should regulate with LOX tank pressure, but remains low during main flow also. Plots of SV0304 signal shows SV0403 remained open to try to regulate pressure. Maybe LN2 was leaking or maybe LOX vent valve inadvertently opened to release LN2. Same behavior for PT0301 and PT0205 during LOX a/s. Three "prestarts" were req'd to pressurize LOX tank initially. Same LOX vent valve problem suspected. All LOX venturi inlet pressures matched in this test, unlike FLT'50 when PT0363 was reading higher. TT0156 (TH#5 fuel mfd temp.) worked fine during ss and fuel a/s, but registered 400 F during water a/s and LOX a/s. Near end of LOX a/s, TT0156 drops to same level as TT0152 briefly and then spikes again and levels out at zero. Next scheduled test on 8/6 will investigate LOX leak further by visually checking system with LN2 during blowdown.
GRUN0053 8/6/98 leak check	Ground test to locate LOX leaks detected in FLT'50. LN2 used in LOX system - visually checked for leaks during 2 LOX autosafes. In 1st a/s, no leaks observed, but 2nd a/s showed some discoloration exiting B-nut on engine attachment. Came from a RD fitting that was safety wired - leakage was thru B-nut. RD recommended re-torquing to see if fitting moved. When torque was checked on 8/7/98, movement was observed, so fitting was re-torqued and safety wire was reinstalled. Also, suspect LOX vent valve opened sometime during flow, since tape covering had come off. Plan to get valve refurb'ed, reworked, replaced? Data for LOX tank (PT0301) and PT0205 (u/s of tank) resembled data for GR'52 suggesting leak or vent valve problem. TT0156 (TH#5 fuel mfd temp.) appeared to work initially, but appears to fail during first a/s when it read 400 F again - continues to read this high for remainder of test. Also, after test was finished, controller aborted due to servo amp over temp. Checking on this further to see if incident was "real" or not.

Table 12. Additional notes for GRUN0019–GRUN0063 tests (Continued).

Test #	Notes
GRUN0054 8/14/98 Flt. cold flow (grounded)	Ground test with LN2 to visually check for LOX system leaks after re-torquing leaky fitting from GR'53. Three cold flows + LOX a/s + water a/s performed. 1st cold flow aborted. 1st cold flow aborted in SS when TT0364 failed to show appropriate drop in LOX temp. Turned out to be a software problem that read all temps incorrectly. After resetting - 2 subsequent cold flows successfully performed. After 2nd cold flow, audibly heard leak that was found at inlet side of main LOX valve (PV0301). Will replace o-ring (k-seal) but inspections did not indicate o-ring was bad. TT0156 still not working properly throughout test.
GRUN0055 8/19/98 Flt. cold flow (grounded)	Ground test with LN2 to visually check for LOX system leaks after working on LOX valve seal. Two cold flows + two LOX a/s + water a/s performed. LOX valve (PV0301) still leaked. TT0156 appears to be inop completely now. Checkouts show its likely the 'ducer itself - can't be fixed without breaking into engine. Will leave inop. To estimate LOW side fuel manifold temps, add 9 degrees to TT0152. LOX manifold pressures appear to be increasing - they are slightly higher in all thrusters for this test compared to other tests. Is this a result of fixing LOX leak discovered at engine's B-nut connection? Engine LOX leak that was fixed after GR'53 was actually only on the HIGH thrust side of the engine - downstream of the 100% venturi, upstream of thrusters 1-4. So, fixing this leak might explain the higher manifold pressures for TH#1-4, but not TH#5-8, which actually showed even higher pressure trends than TH#1-4. Check data from next test to see if all pressures continue to increase, stay the same, or go back to previous levels. Water a/s showed manifold pressure was high enough for controller to relieve pressure 15 times. Discovered a bad pressure regulator in canoe GHe system. While servicing regulator valves, discovered o-rings were missing - searching water system for them (boroscoping water tanks to see if they can find them.)
GRUN0056 9/11/98 Flt. cold flow (grounded)	Ground test with LN2 to visually check for LOX system leaks after installing teflon coated SS K-seal in fitting u/s of LOX valve (PV0301) to try to fix recurring leak. One of the canoe He regulators was out, so water pressure is reduced throughout test. Low canoe helium pressure caused abort in 3rd main flow (3ss). During 1st main flow (1ss) leak observed in LOX prechill line. Aborted to retorque fitting. No leakage observed in subsequent main flows and autosafe.
GRUN0057 9/18/98 Flt.cold flow (grounded)	Ground test with LOX to visually check for LOX system leaks. One of the canoe He regulators still out, so water pressure was low again. 2 main flows and 1 a/s performed Shortly after 1st main flow, model O2 levels rose to about 1.5%, followed by rise in canoe O2 level. After 2nd main flow, model O2 level rose to below 1%, with little response from canoe O2 level. After LOX system a/s, model O2 level rose to about 3.3%.
GRUN0058 9/30/98 Flt.cold flow (grounded)	Ground test with LOX to check for LOX system leaks with O2 sensors (pod sealed) Main flow aborted early with low water pressure (one of the canoe He regulators still out, limiting water pressure) LOX leaks detected with sensors during LOX autosafe - model O2 levels rose to about 4.5%, followed by rise in canoe O2 level.
GRUN0059 10/2/98 Flt.cold flow (grounded)	Ground test with LOX to check for the LOX system leaks with O2 sensors. 2 main flows + 1 a/s performed. Model O2 levels rose to about 6-7% after 1st main flow (suspect unsecured LO2 manual vent valve panel allowed purge flow to escape) O2 levels in 2nd main flow and autosafe were similar to levels measured in GR'57 & '58
GRUN0060 10/7/98 Flt.cold flow (grounded)	Ground test with LN2 to visually check for LOX system leaks. All accessible LOX system joints & fittings were bagged using clear plastic material. 2 LOX system cold flows + autosafe performed During autosafe, some indication of a leak downstream of main LOX valve. LOX tank was reserviced to fill with LN2 and 3rd cold flow and 2nd a/s performed. (2 hour hold used to allow LOX system to warm up) 3rd a/s attempted, but no LN2 available

Table 12. Additional notes for GRUN0019–GRUN0063 tests (Continued).

Test #	Notes
GRUN0061 10/9/98 Flt.cold flow (grounded)	Ground test with LN2 to visually check for LOX system leaks. No leaks observed in 2 main flows and a/s.
GRUN0062 10/16/98 Flt.cold flow (grounded)	Ground test with LOX to check for leaks using O2 sensors. 3 handheld O2 sensors set up to detect leaks around engine interface and sewer pipe. Pod N2 purge used a 3X orifice. 2 cold flows + 1 a/s planned. Handheld detectors inop. Systems display that supplies abort info was inop due to OFP change Controller aborted both cold flow attempts - suspected problems with newly installed canoe He regulator. Attempted water a/s failed due to incorrect button presses (H2 a/s was selected rather than H2O). Caused aborted H2 a/s since blocking valve was closed.
GRUN0063 10/21/98 Flt.cold flow (grounded)	Ground test with LOX to check for leaks using O2 sensors. Pod N2 purge used a 3X orifice size. 2 LOX blows, 2 water a/s, & 1 LOX a/s completed. Max. O2 levels detected were ~ 2% after 1st blow, 1% after 2nd, & 4.5% after LOX a/s. 1st water a/s - flowed very little water, with a/s completing early due to low water tank pressure. 2nd water a/s - expelled water until controller aborted due to water inlet pressure max. R/L of 660 psi (PT0451 had a 300 psi offset at ambient conditions due to damage from previous ground test) Data shows 80% LOX venturi inlet pressure reading ~ 20 psi higher during main flow (~ 10 psi higher during prechill). Similar behavior to FLT'50. All other LOX system data remained consistent with previous tests.
FLT0051 10/29/98 Flt. leak chck	Flight test with LOX to check for leaks using O2 sensors. 1 LOX blow and 1 LOX a/s performed at 31,000 ft and Mach # = 0.9 80% LOX venturi inlet pressure returned to nominal level. All other LOX system and engine data looked nominal and consistent. Max. O2 levels detected were ~ 6.2% after main blow, & ~ 9.5% after LOX a/s.

APPENDIX G—Water System Results

Appendix F summarizes the steady-state data for the water system in each test.

G.1 Flow Rate Calculations

Initially in the LASRE program, a turbine flowmeter was located in the coolant's exit line to measure the water's flow rate. This flowmeter was eventually removed when the water autosafe procedure was added to alleviate concerns about overspinning its turbine blades (when all the water was expelled, high-speed GHe would be flowing across the flowmeter). After the flowmeter was removed, the coolant's flow rate was estimated by scaling the resulting pressure drops between subsequent tests.

Example:

GRUN0020—with F/M data:

$$\dot{m} = 39.6\,\mathrm{lb_m} / \mathrm{sec}; \ \text{engine } \Delta P = 389 \text{ psi}$$

GRUN0022—F/M removed:

$$\text{engine } \Delta P = 411 \text{ psi} .$$

Since resistance, R, through the engine should be the same,

$$R = \frac{\Delta P \cdot \rho}{\dot{m}^2} . \tag{1}$$

Since P=constant

$$\frac{\dot{m}^2)'}{\dot{m}^2} = \frac{\Delta P'}{\Delta P} . \tag{2}$$

Estimated for GRUN0022 by solving equation (2):

$$\dot{m}' = \sqrt{\left(\frac{411}{389}\right)(39.6 \text{ lb}_\mathrm{m} / \sec)^2} = 40.7 \text{ lb}_\mathrm{m} / \sec .$$

In the tests where freezing the coolant in the engine was a problem, the flow rate was estimated by scaling relative to the ΔP from the water tank to the engine's inlet, since the resistance within the engine would be changing due to the freezing coolant.

Water system performance during GRUN0036 is shown in figure 23 (pressures responded as expected).

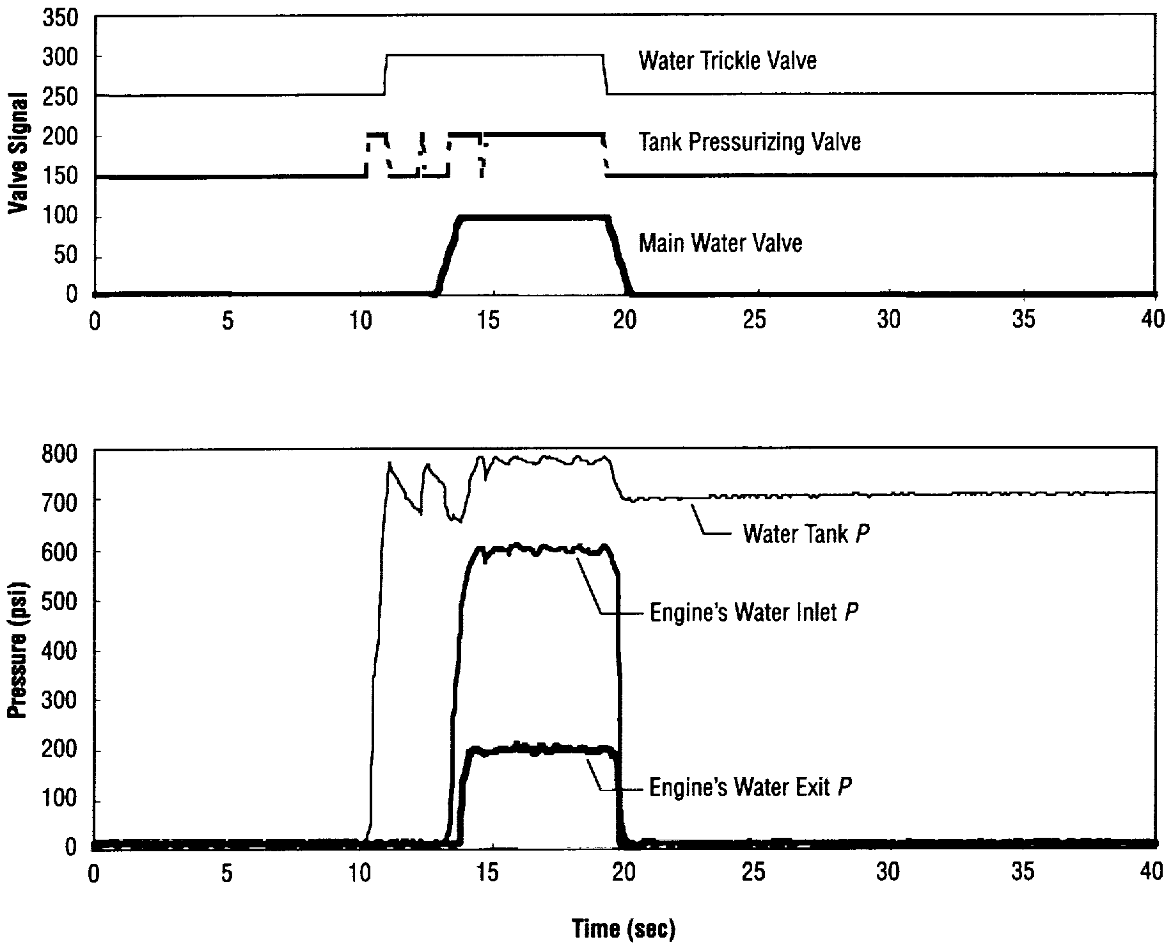


Figure 23. Water system performance during GRUN0036.

APPENDIX H—LOX System Results

The LOX system performance during GRUN0036 is shown in figure 24. LOX system pressure and temperatures responded as expected.

Appendix F provides the steady-state data and calculation results for each test.

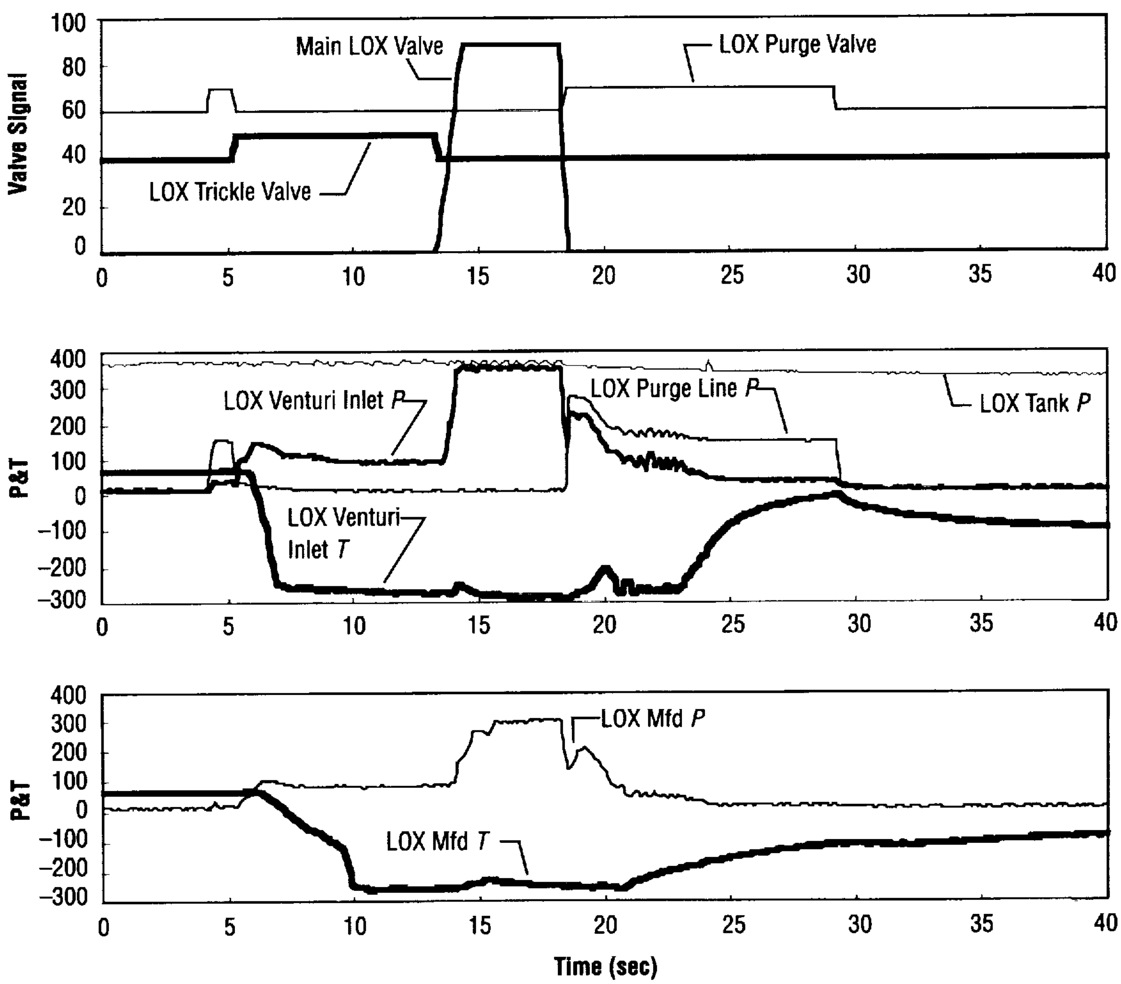


Figure 24. LOX system performance during GRUN0036.

H.1 LOX Flow Rate Calculations

LOX flow rates were calculated based on the venturi inlet pressures and temperatures. These inlet conditions, along with the venturi sizes, were used to determine the corresponding flow rates for cavitating flow.

While the 20- and 80-percent venturies included throat pressure measurement to check for cavitation, the overall pressure ratio across each venturi could also be used. Cavitation was ensured if P_{out}/P_{in} = 0.85 or less (although cavitation can occur even when the pressure ratio is higher). Using the LOX manifold pressure as P_{out} (assuming negligible pressure loss between the venturi exit and the inlet of the thrusters), the resulting pressure loss in each venturi was checked.

Example (GRUN0023):

100-percent LOX venturi: P_{in} = 352 psia

Thruster No. 1 LOX manifold: P_{out} = 197 psia.

Resulting pressure ratio = 197/352 = 0.56, so cavitation was ensured on the HIGH thrust side of the engine.

80-percent LOX venturi: P_{in} = 345 psia

Thruster No. 5 LOX manifold: P_{out} = 209 psia.

Resulting pressure ratio = 209/345 = 0.61, so cavitation was insured on the LOW thrust side of the engine. Cavitation was also confirmed in the 80-percent venturi when the resulting throat pressure measured 33 psia. With vapor conditions obviously resulting in the throat based on this pressure, cavitation was definitely occurring.

To further calculate the actual flow rates, the incompressible flow equation was used:

$$\dot{m} = AC_d\sqrt{2g_c\rho\Delta P} \quad , \tag{3}$$

where

A = flow area in venturi throat, in.^{2}

C_d = venturi discharge coefficient

g_c = gravitational constant = 32.2 lb_m ft/lb_f s^2

ρ = liquid density of LOX, lb_m/ft^3

ΔP = pressure loss from venturi inlet to venturi throat, psi.

Example (GRUN0023):

For 100-percent venturi:

$D_t = 0.28$ in. and $C_d = 0.989$; $\therefore AC_d = (\pi/4)(0.28)^2(0.989) = 0.0609$ in.^{2}

$P_{in} = 352$ psia and $T_{in} = -266$ °F.

For a cavitating venturi, the resulting throat pressure equals the vapor pressure of LOX. So, using MIPROPS (a computer code for thermodynamic properties of several fluids), the vapor pressure of LOX at –266 °F was found:

$$P_{vapor} = 66.5 \text{ psia}$$

$$\therefore \Delta P = 352.0 - 66.5 = 285.5 \text{ psia.}$$

The density of the LOX was found using MIPROPS and the inlet conditions of the venturi:

$$\rho = 66.925 \text{ lb}_m/\text{ft}^3 \text{ (at 352 psia and } -266 \text{ °F).}$$

Finally solving equation (3),

$$\dot{m} = 0.0609 \text{ in.}^2 \sqrt{\frac{2(32.2 \text{ lb}_m \cdot \text{ft} / \text{lb}_f \cdot \text{s}^2)(65.925 \text{ lb}_m / \text{ft}^3)(285.5 \text{ lb}_f / \text{in.}^2)}{144 \text{ in.}^2 / \text{ft}^2}} = 5.6 \text{ lb}_m / \text{sec} \quad .$$

H.2 LOX Side AC_d Calculations

For each thruster in the engine, the adjusted flow area, AC_d, of the LOX side of the injector was calculated for each test. These values were used as a reference for the hardware. Significant changes to the flow areas of the injectors could be indications of hardware anomalies.

These flow areas were also calculated using the incompressible flow equation, along with the conditions measured in each thruster:

$$AC_d = \frac{\dot{m}}{\sqrt{2 g_c p \Delta P}} \quad , \tag{4}$$

where, in this case,

$$\Delta P = P_{\text{LOX mfd}} - P_c \quad .$$

Example (GRUN0037):

Thruster No. 1: LOX mfd $P = 309$ psia:

$$\text{LOX mfd } T = -248\ °\text{F}$$

$$P_c = 217 \text{ psig} = 232 \text{ psia.}$$

Using the density of LOX at the average pressure in the thrusters:

$$\text{Ave } P = (309 + 232)/2 = 270.5 \text{ psia}$$

$$\rho = 62 \text{ lb}_\text{m}/\text{ft}^3 \text{ (at 270.5 psia and } -248\ °\text{F).}$$

LOX flow rate to thruster No.1:

$$\dot{m} = \frac{\dot{m} \text{ from } 100\% \text{ venturi}}{4} = \frac{5.9}{4} = 1.48 \text{ lb}_\text{m} / \text{sec} .$$

So solving equation (4),

$$AC_d = 1.48 \text{ lb}_\text{m} / \text{sec} \Bigg/ \sqrt{\frac{2(32.2 \text{ lb}_\text{m} \cdot \text{ft} / \text{lb}_\text{f} \cdot \text{s}^2)(309 - 232)\text{lb}_\text{f} / \text{in.}^2 (62 \text{ lb}_\text{m}\text{ft}^3)}{144 \text{ in}^2 / \text{ft}^2}} = 0.032 \text{ in.}^2$$

Results for the LOX side flow areas in all cold flows were plotted in figure 25.

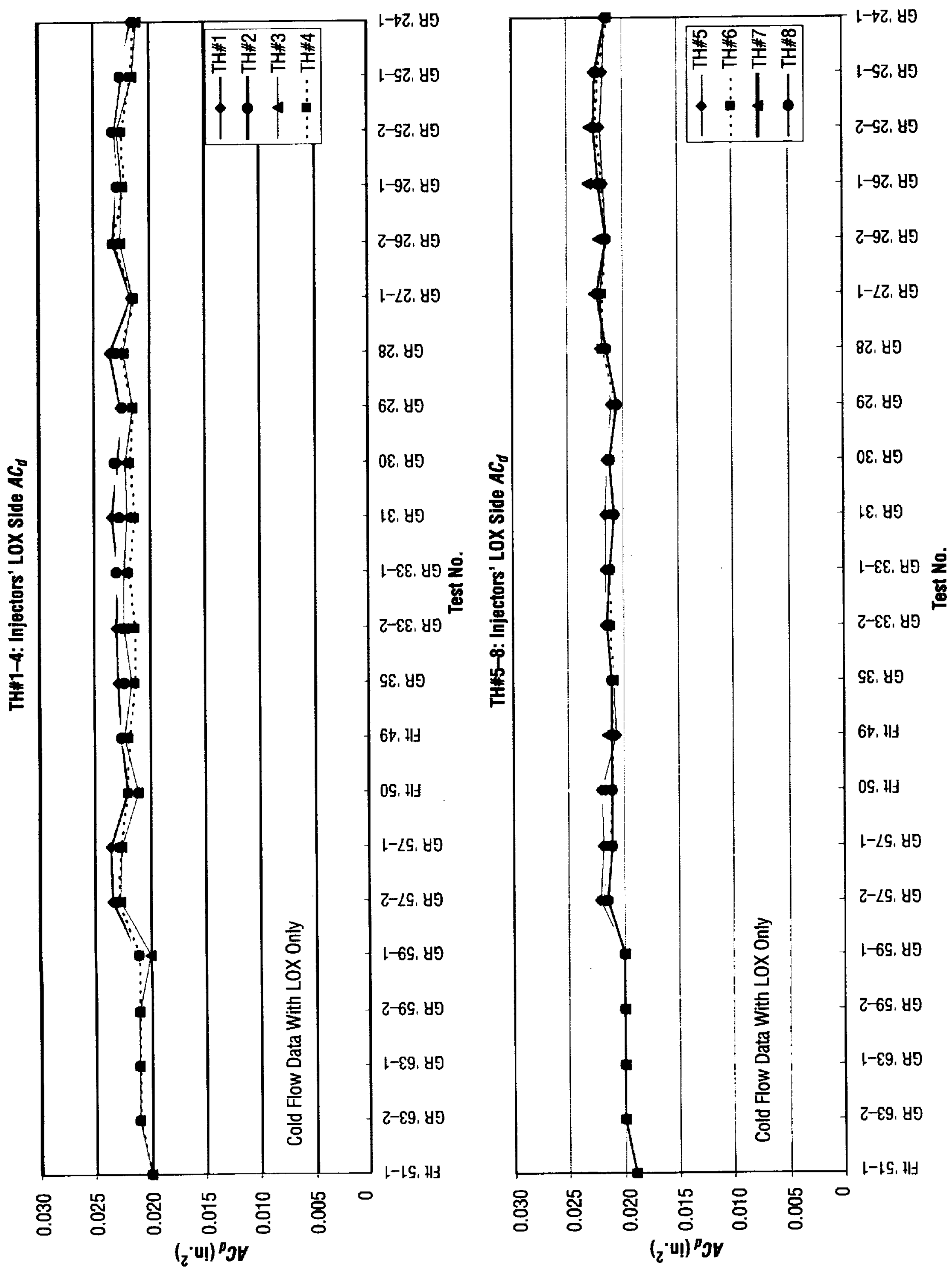


Figure 25. LOX side flow area data.

APPENDIX I—Fuel System Results

Figure 26 shows the fuel system performance during GRUN0036. Appendix F provides the steady-state data and calculation results for each test.

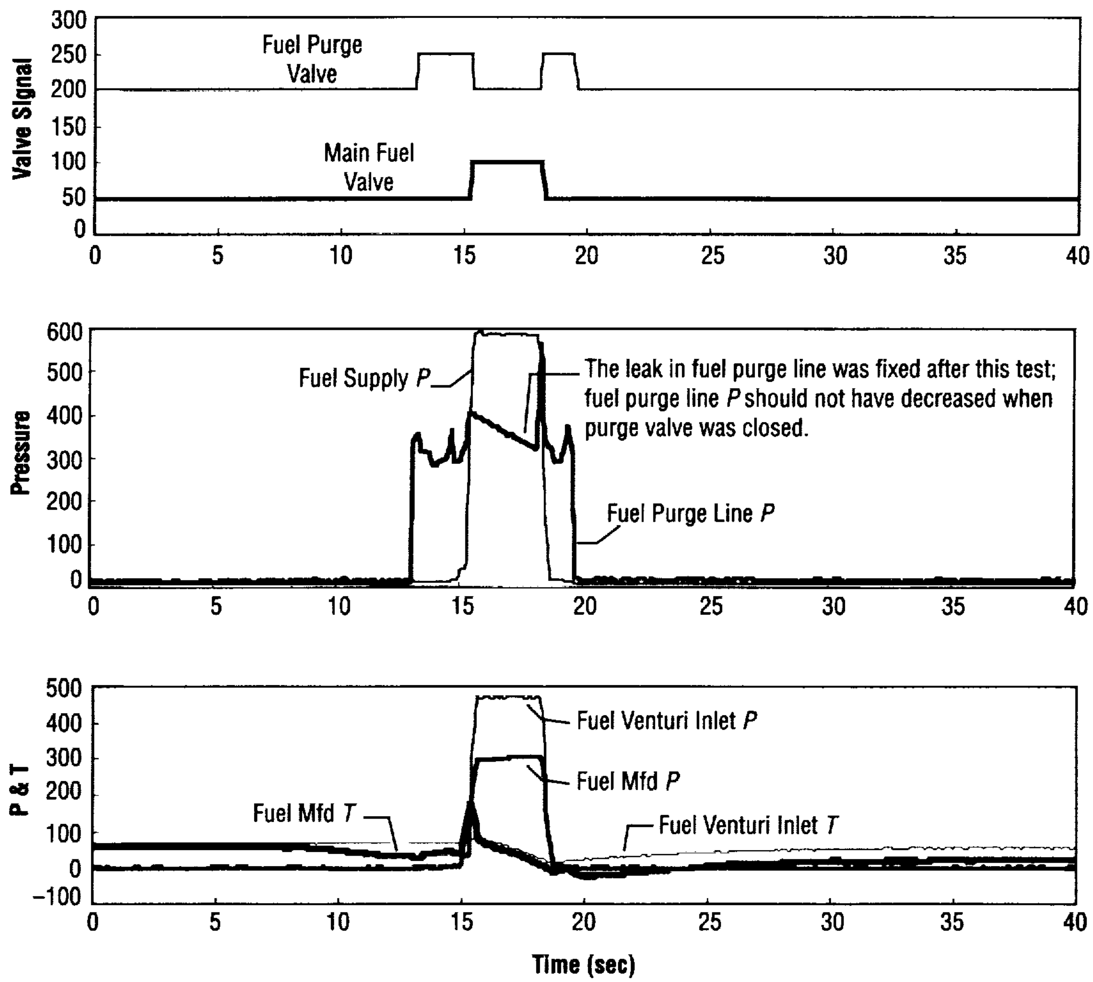


Figure 26. Fuel system performance during GRUN0036.

I.1 Fuel Flow Rate Calculations

Fuel flow rates were calculated with the compressible flow equation:

$$\dot{m} = \left(AC_d\right)PD\sqrt{\frac{\gamma g_c}{Z\mathbf{R}T}} \ , \tag{5}$$

where

A = flow area in venturi throat, in.^{2}

C_d = venturi discharge coefficient

P = inlet pressure to the venturi, psia

T = inlet temperature to the venturi, °R

$\mathbf{R}$ = universal gas constant, lb_f ft/lb_m °R

g_c = gravitational constant (32.2 lb_m ft/lb_f s^2)

γ= specific heat ratio

$$Z = \text{compressibility function} = P/\rho\,\mathbf{R}T \tag{6}$$

$$D = M\left(1 + \frac{\gamma - 1}{2}M^2\right)^{\frac{-(1+\gamma)}{2(\gamma-1)}} \ . \tag{7}$$

Example (GRUN0038):

At 100-percent venturi:

Inlet P = 474 psig = 489 psia
Inlet T = 51 °F = 511 °R
Ave. fuel manifold pressure (TH No. 1–4) = 239 psig = 254 psia.

For GHe, $\mathbf{R}$ = 386 ft lb_f/lb_m °R and γ = 1.67
At 489 psia and 511 °R, ρ_{He} = 0.351 lb_m/ft^3; using equation (6):

$$Z = \frac{\left(489\ lb_f / in.^2\right)\left(144\ in.^2 / ft^2\right)}{\left(0.351\,lb_m / ft^3\right)\left(386\ ft \cdot lb_f / lb_m \cdot °R\right)\left(511\,°R\right)} = 1 \ .$$

Note: For the GH_2 and GHe conditions used in this test program, Z=1 was assumed for all calculations.

Flow through the venturi was choked at the throat (P_{out}/P_{in} = 254/489 ~0.5), so M=1. Therefore, solving for equation (7):

$$D = 1\left(1 + \frac{1.67-1}{2}(1)^2\right)^{\frac{-(1+1.67)}{2(1.67-1)}} = 0.5625 \ .$$

Values of D are also tabulated in most compressible flow tables for various γ and pressure ratios.

For the 100-percent venturi, with a throat diameter of 0.685 in. and a C_d = 0.97, its AC_d is 0.3575 in.^{2}

Finally solving equation (5),

$$\dot{m} = (0.3575\,\text{in.}^2)(489\,\text{lb}_f / \text{in.}^2)(0.5625)\sqrt{\frac{(1.67)(32.2\,\text{lb}_m \cdot \text{ft} / \text{lb}_f \cdot \text{s}^2)}{(1)(386\,\text{ft} \cdot \text{lb}_f / \text{lb}_m \cdot {}^\circ\text{R})(511{}^\circ\text{R})}} = 1.62\ \text{lb}_m / \text{sec} \ .$$

For hot-fires with GH_2, γ= 1.4 and **R** = 766 $\text{lb}_f\,\text{ft/lb}_m$ °R and D = 0.5787 when flow is choked through the venturi.

Choked flow conditions were checked with the pressure ratio across the venturi:

for γ= 1.4, P/P_t = 0.53 or less creates choked flow

for γ= 1.67, P/P_t = 0.5 or less creates choked flow,

where

P = downstream pressure, such as the fuel manifold pressure

and

P_t = total upstream pressure = venturi inlet pressure.

The total fuel flow rate for the LOW thrust side was the sum of the flow rate through the 80- and 20-percent venturies.

Note: For the hot-fires, GRUN0037 and GRUN0036, the fuel venturies during mainstage did not choke (based on pressure measurements). So, values for D were found from a compressible flow table for γ=1.4 at the actual pressure ratios.

Example (GRUN0037):

100-percent fuel venturi:

inlet pressure, $P_t = 466$ psig

average downstream pressure, at the fuel manifolds:

$$P = \frac{307 + 304 + 305 + 308}{4} = 306 \text{ psig}$$

$$\text{Across venturi, } \frac{P}{P_t} = \frac{(306 + 15)\,\text{psia}}{(466 + 15)\,\text{psia}} = 0.67 \quad .$$

For $\gamma = 1.4$ at $P/P_t = 0.67$, $D = 0.5523$ (M=0.78), instead of D= 0.5787 for M=1.

So, D=0.5523 was used to calculate the fuel flow rate through the 100-percent venturi in GRUN0037.

I.2 Fuel Side AC_d Calculations

For each thruster in the engine, the flow area, AC_d, of the fuel side of the injector was calculated for each test. These values were used as a reference for the hardware. Significant changes to the flow areas of the injectors could be indications of hardware anomalies.

These flow areas were also calculated using the compressible flow equation, along with the conditions measured in each thruster:

$$AC_d = \frac{\dot{m}}{PD\sqrt{\frac{\gamma g_c}{Z\mathbf{R}T}}} \quad . \tag{8}$$

Assume $Z = 1$ for GHe or GH_2.

Example (GRUN0037):

Thruster No. 1:

fuel mfd P = 307 psig = 322 psia
fuel mfd T = 18 °F = 478 °R
P_c = 217 psig = 232 psia

$$\frac{P}{P_t} = \frac{232}{322} = 0.72 \rightarrow D\text{=}0.5293 \text{ for } \gamma = 1.4$$

$$\dot{m} = \frac{\dot{m} \text{ from 100\% venturi}}{4} = \frac{1.03 \text{ lb}_\text{m} / \text{sec}}{4} = 0.26 \text{ lb}_\text{m} / \text{sec} \quad .$$

Solving equation (8)

$$AC_d = \frac{0.26\ \text{lb}_\text{m}/\text{sec}}{(322\ \text{lb}_\text{f}/\text{in.}^2)(0.5293)\sqrt{\dfrac{1.4(32.2\ \text{lb}_\text{m}\cdot\text{ft}/\text{lb}_\text{f}\cdot\text{s}^2)}{(766\ \text{lb}_\text{f}\cdot\text{ft}/\text{lb}_\text{m}\cdot°\text{R})(478\ °\text{R})}}} = 0.137\ \text{in.}^2$$

For the cold flows with GHe, flow across the fuel side of the injector was choked, so $D = 0.5625$; but for the hot-fires, D was found relative to the resulting pressure ratio across the injector.

Results for the fuel side flow areas in all cold flows (with GHe) were plotted in figure 27. Note the change in flow area after the ignition tests were attempted. This likely occurred due to TEA-TEB residue that built up in the fuel annuli or BLC holes. However, plenty of fuel side flow area remained to provide appropriate hot-fire test conditions (see fig. 28). This residue on the fuel side did not seem to pose any threat to the hardware. The decrease in fuel side AC_d's produced no effect on P_c's. It was reasonable to assume that adequate fuel side flow areas still existed and venturies were still controlling the fuel flow rate to the desired (and consistent) levels.

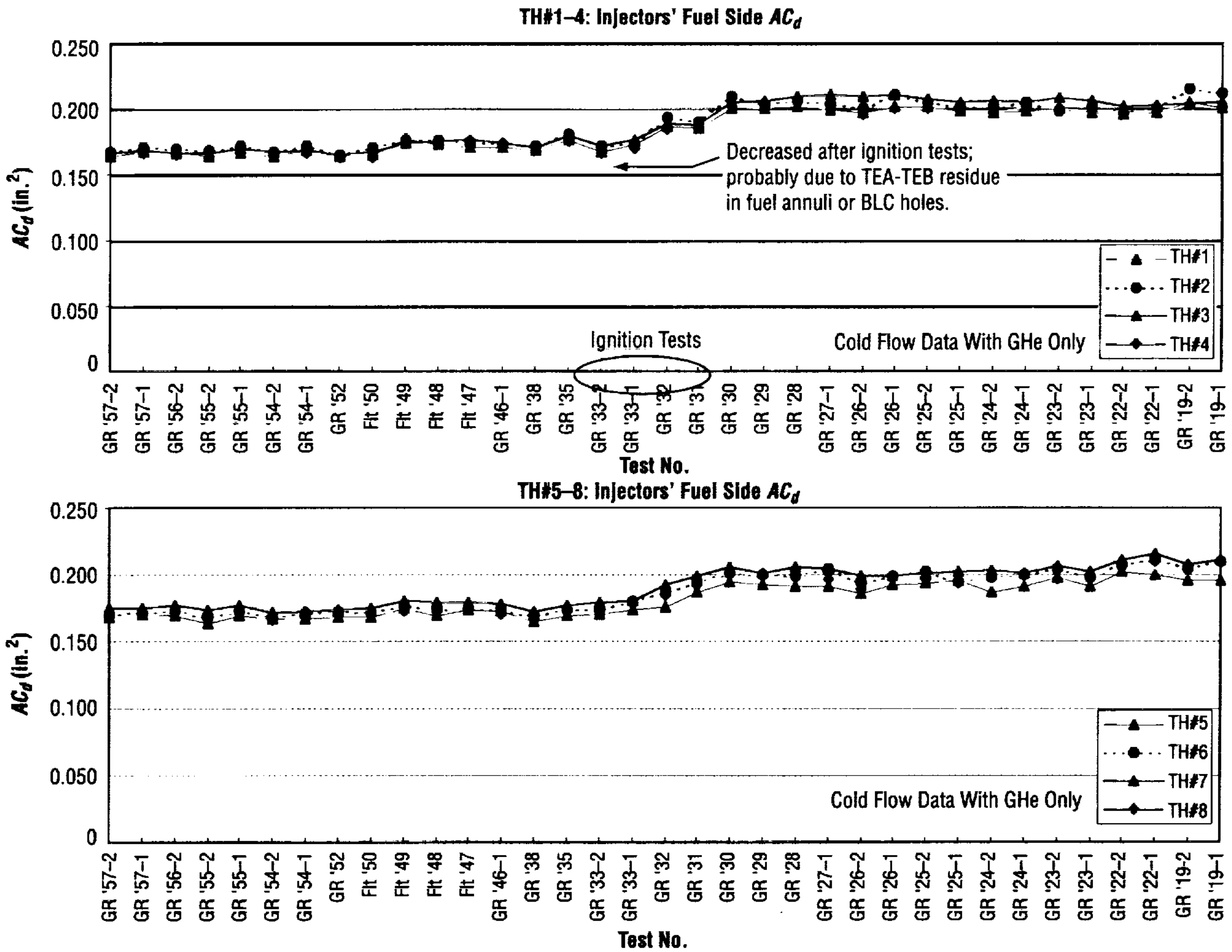


Figure 27. Fuel side AC_d results.

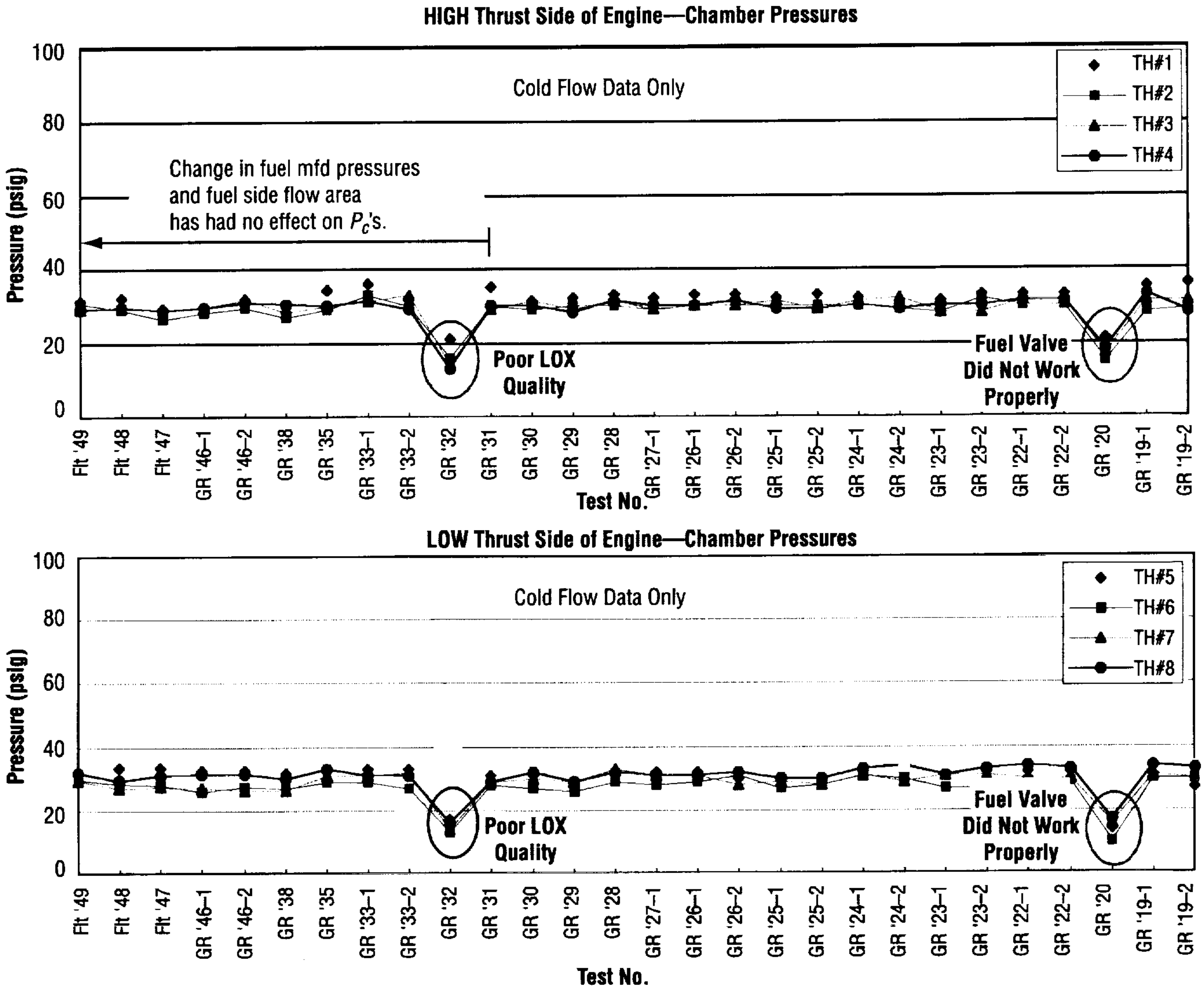


Figure 28. Effect of fuel side AC_d changes on P_c's.

APPENDIX J—Ignition Test Results

Resulting chamber pressures during ignition test (GRUN0033) are shown in figure 29. Appendix F includes the steady-state data for each ignition test (GR'31–33).

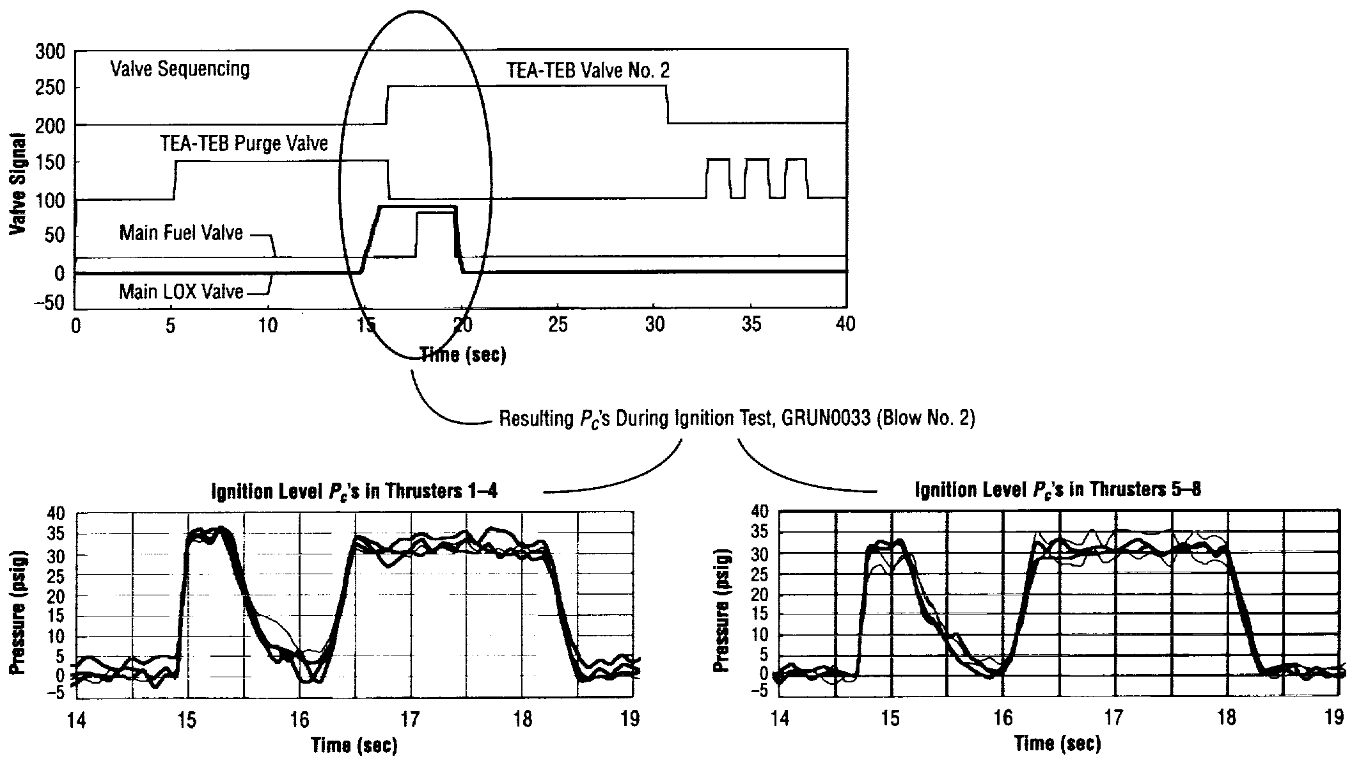


Figure 29. Thruster chamber pressures during ignition test.

J.1 TEA-TEB Flow Rate Calculations

The TEA-TEB flow rate was estimated with the incompressible flow equation:

$$\dot{m} = AC_d\sqrt{2g\rho\Delta P} \quad , \tag{9}$$

where

AC_d = flow area of the TEA-TEB flow control orifices
(dia = 0.026 in., C_d ~0.6 assumed)

g_c = gravitational constant = 32.2 $lb_m \cdot ft/lb_f \cdot s^2$

ΔP = pressure drop across orifice, psi

ρ = density of TEA-TEB = 44.5 lb_m/ft^3 .

Example (GRUN0033):

During ignition phase between LOX and TEA-TEB:

TEA-TEB supply pressure to engine = 693 psia (PT0651)
Average thrust chamber pressure = 45 psia

With an orifice diameter of 0.026 in. and assuming a C_d=0.6, AC_d was 3.186×10^{-4} in.^{2} for each thruster ignition port.

Solving equation (9)

$$\dot{m} = (3.186\times10^{-4} \text{ in.}^2)\sqrt{\frac{2(32.2 \text{ lb}_m \cdot \text{ft} / \text{lb}_f \cdot \text{s}^2)(693-45)\text{lb}_f / \text{in.}^2}{144 \text{ in.}^2\text{ft}^2}} = 0.036 \text{ lb}_m / \text{sec per thruster} \quad .$$

APPENDIX K—Hot-Fire Test Results

System performance during GRUN0036 is shown for LOX (fig. 30), fuel (fig. 31), TEA-TEB (fig. 32), water (fig. 33), and engine (fig. 34) systems. All systems responded as expected. Results were similar for hot-fire GRUN0037. Figure 35 shows the chamber pressure behavior during hot-fire. During mainstage, chamber pressures continue to rise slightly due to increasing fuel flow rate.

The LASRE engine supply systems for GRUN0037 is shown in figure 36. Table 13 lists the performance results for GRUN0037 and GRUN0036. Appendix F provides the steady-state data and calculation results for each hot-fire test, GR'36 and GR'37.

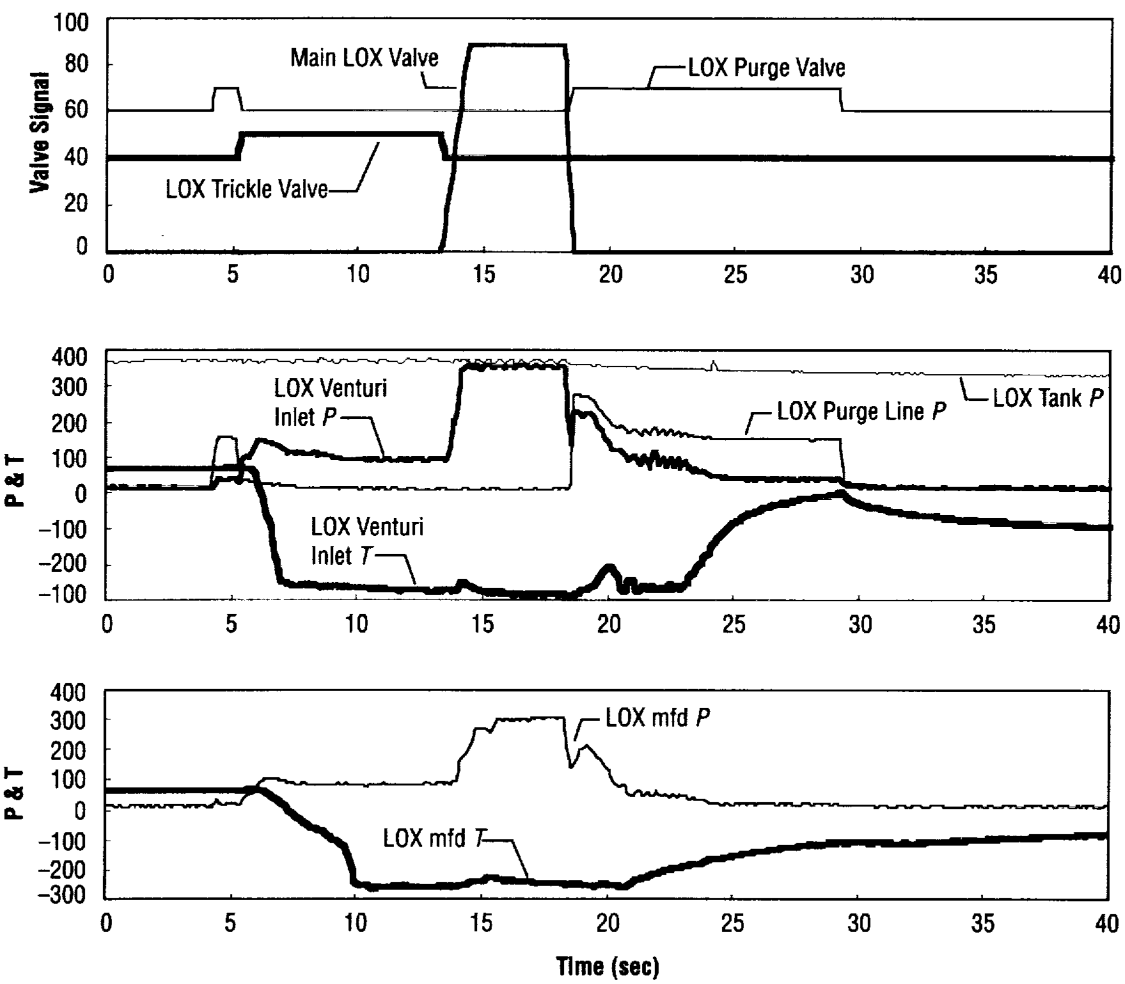


Figure 30. LOX system performance during GRUN0036.

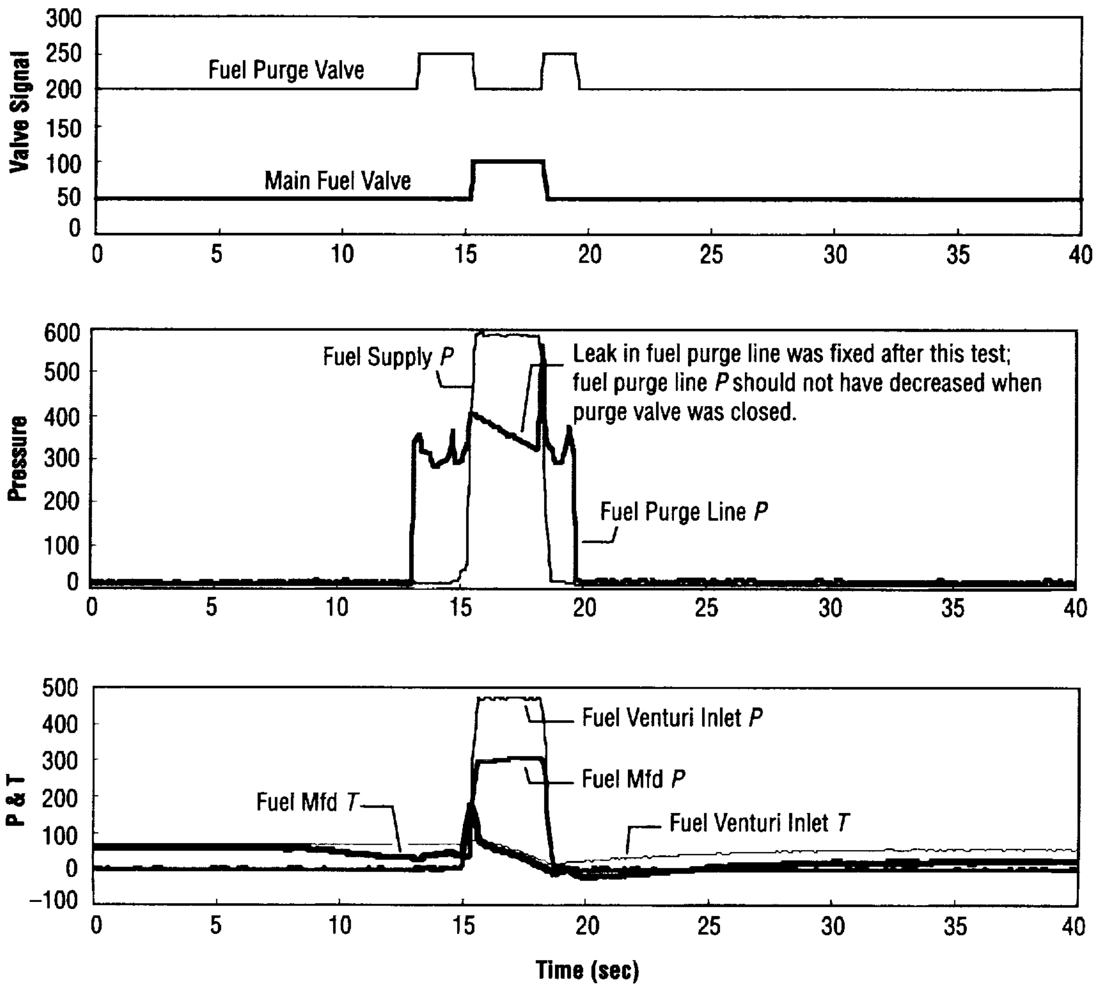


Figure 31. Fuel system performance during GRUN0036.

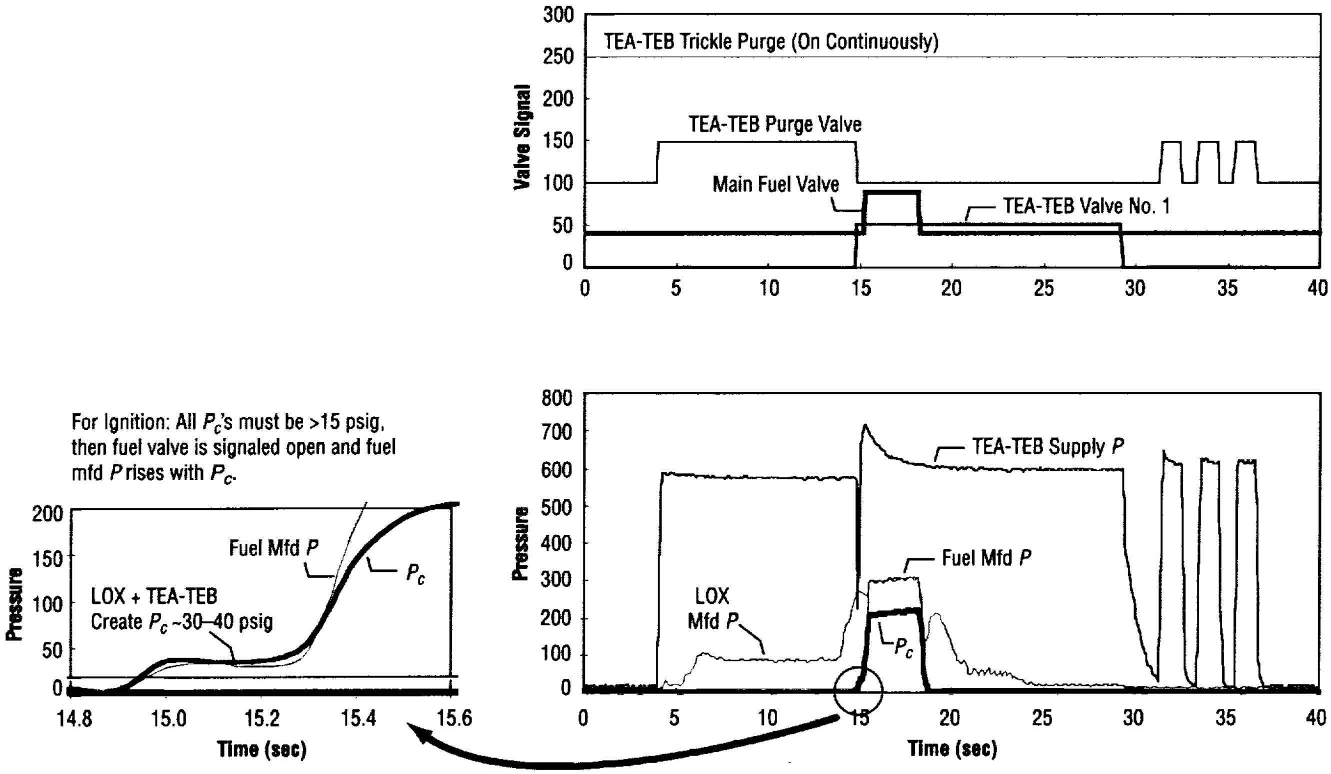


Figure 32. TEA-TEB system performance during GRUN0036.

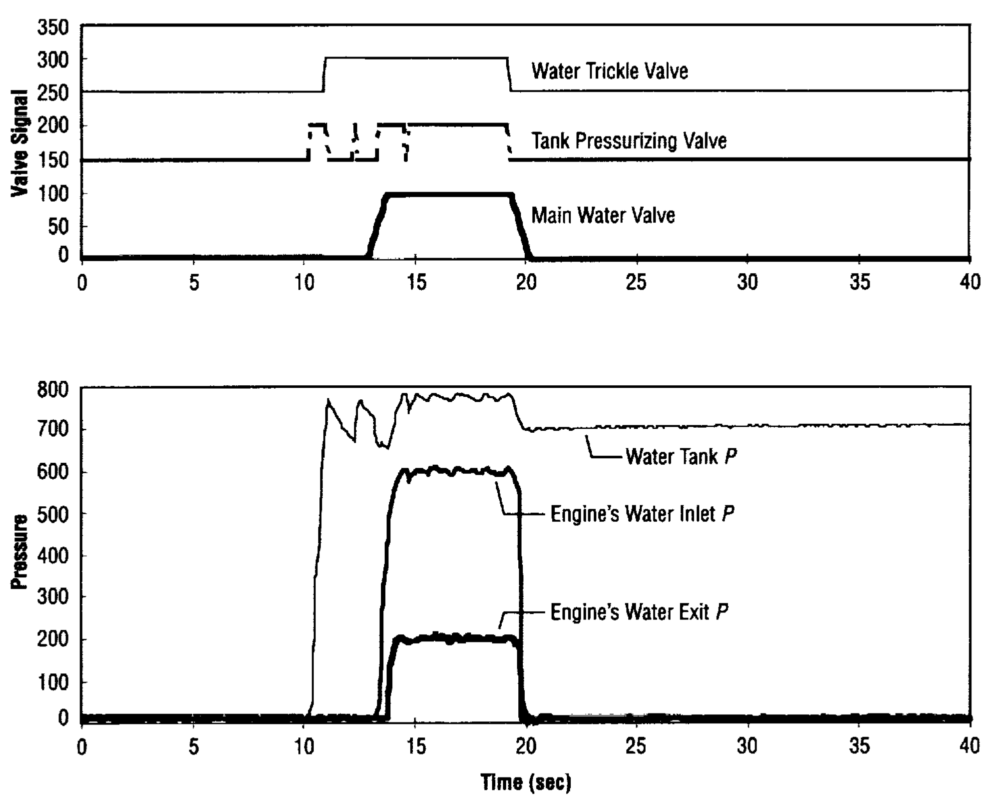


Figure 33. Water system performance during GRUN0036.

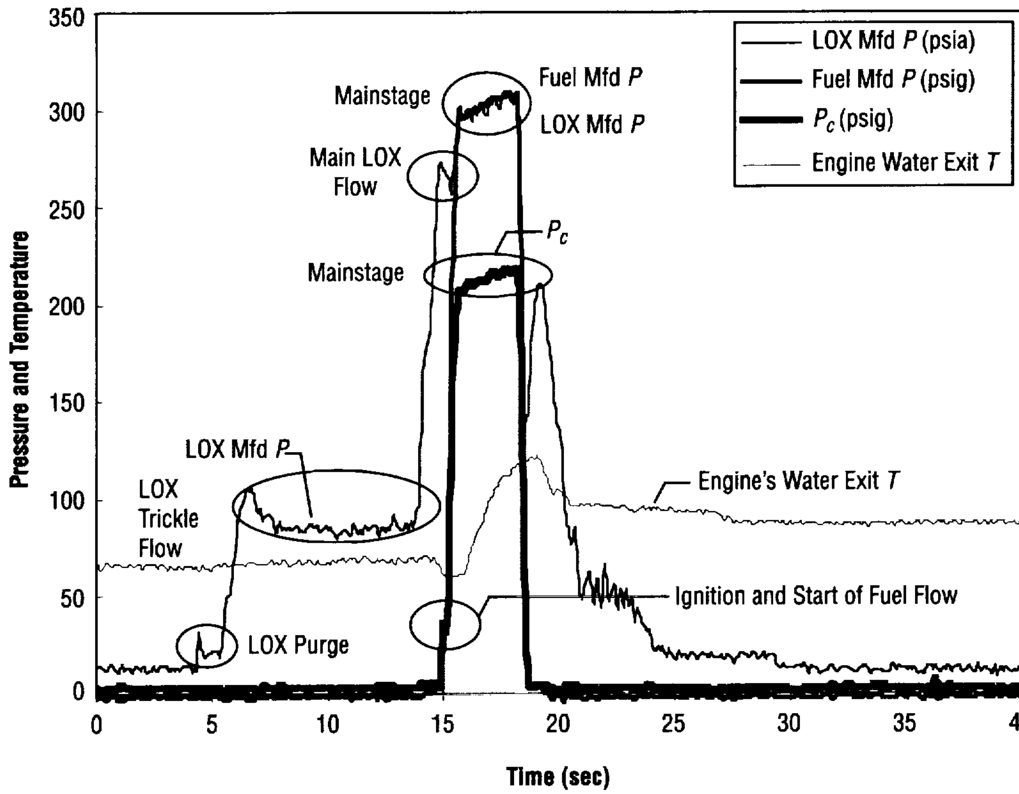


Figure 34. Engine performance during GRUN0036.

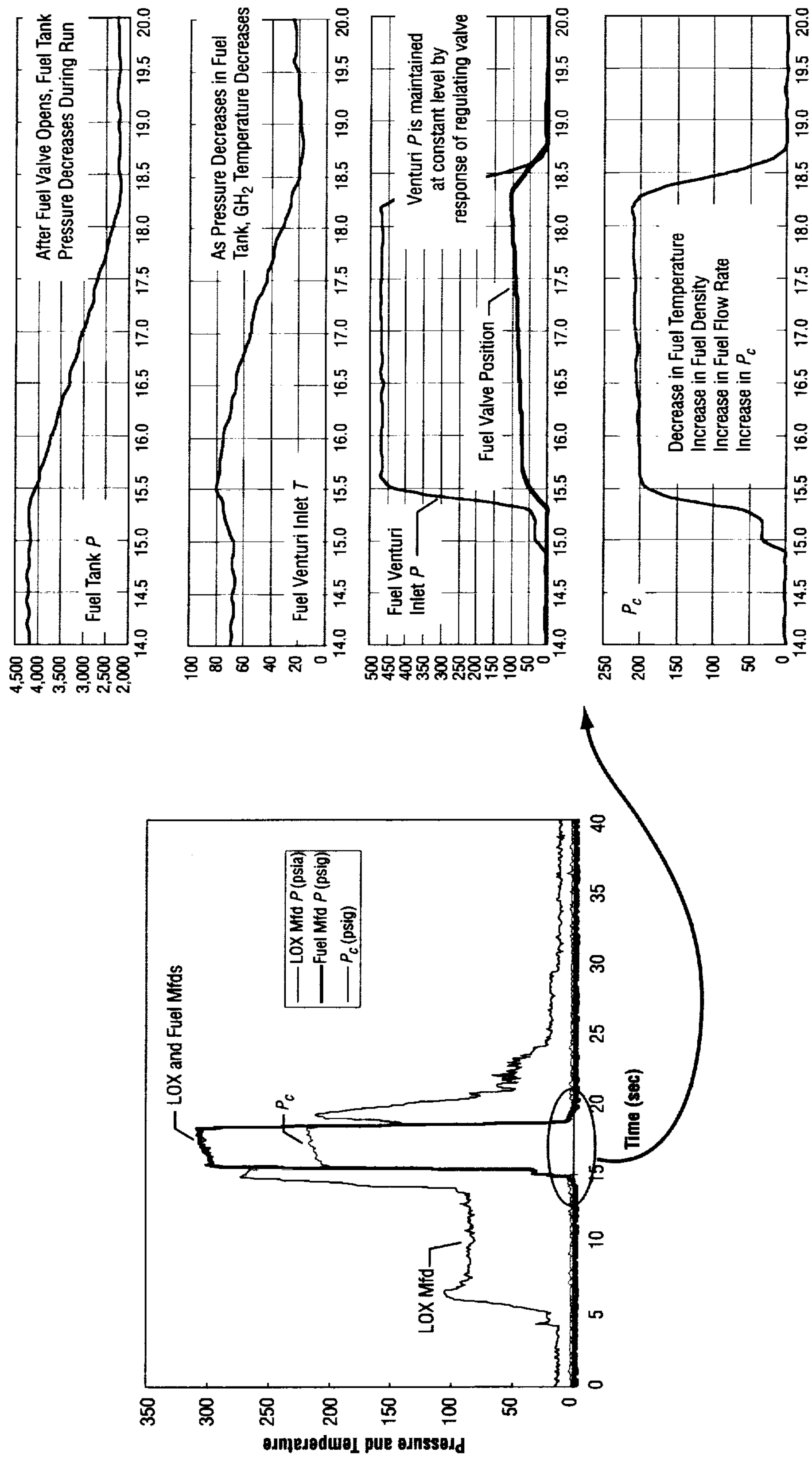


Figure 35. Chamber pressure behavior during hot-fire.

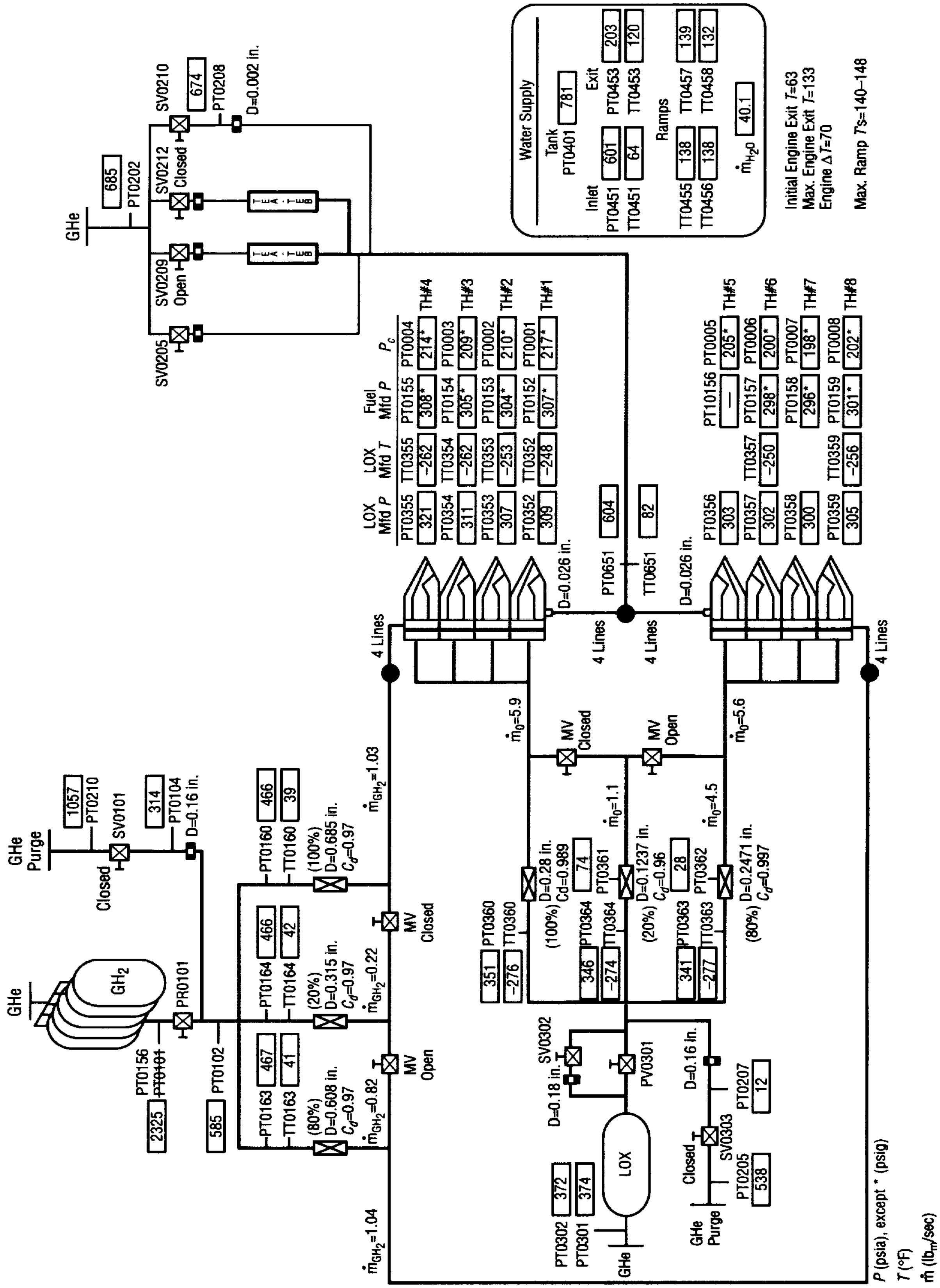


Figure 36. LASRE engine supply systems GRUN0037.

Table 13. Performance results from GRUN0037 and GRUN0036.

Performance	GRUN0037								GRUN0036							
Results	TH#1	TH#2	TH#3	TH#4	TH#5	TH#6	TH#7	TH#8	TH#1	TH#2	TH#3	TH#4	TH#5	TH#6	TH#7	TH#8
total propellant flow rate (lb_m/s)	1.73	1.73	1.73	1.73	1.66	1.66	1.66	1.66	1.76	1.76	1.76	1.76	1.69	1.69	1.69	1.69
LOX mfd. P (psia)	309	307	326	321	303	302	315	305	306	307	327	319	297	299	312	298
LOX mfd. T (F)	-248	-253	-262	-262	-249.94	-250	-256.41	-256	-246.22	-256.46	-263.77	-263.22	-253.37	-253.37	-257.52	-257.52
h (BTU/lb_m) for LOX mfd P & T	*-36.2*	*-40.6*	*-42.3*	*-42.3*	*-37.1*	*-37.1*	*-39.7*	*-39.8*	*-35.4*	*-39.7*	*-43.1*	*-42.7*	*-38.5*	*-38.5*	*-40.6*	*-40.6*
Fuel mfd. P (psig)*	307	304	305	308	298	298	296	301	305	304	303	308	296	296	294	300
P_{atm} at altitude (psia)	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7
Fuel mfd. P (psia)	322	319	319	323	312	312	310	316	320	318	318	323	311	311	309	315
Fuel mfd. T (F)	18	18	18	18	31	31	31	31	10	10	10	10	23	23	23	23
h (BTU/lb_m) for GH_2 mfd P & T	*1587*	*1587*	*1587*	*1587*	*1634*	*1634*	*1634*	*1634*	*1558*	*1558*	*1558*	*1558*	*1605*	*1605*	*1605*	*1605*
Pc (psig)	217	210	209	214	205	200	198	202	218	210	210	212	205	199	197	201
(Convert enthalpies to cal/mol & subtract std. values)																
CEA/CETPC INPUT:																
GH_2 h (cal/mol)	-262.73	-262.73	-262.73	-262.73	-210.56	-210.56	-210.56	-210.56	-294.92	-294.92	-294.92	-294.92	-242.75	-242.75	-242.75	-242.75
GH_2 T (K)	265.45	265.45	265.45	265.45	272.86	272.86	272.86	272.86	261.17	261.17	261.17	261.17	268.1	268.1	268.1	268.1
LOX h (cal/mol)	-2713.1	-2791.2	-2821.4	-2821.4	-2729.1	-2729.1	-2775.2	-2777	-2698.9	-2775.2	-2835.6	-2828.5	-2753.9	-2753.9	-2791.2	-2791.2
LOX T (K)	117.57	115.18	109.9	110.07	116.7	116.7	113.11	113.11	118.77	113.08	109.01	109.32	114.8	114.8	112.49	112.49
Pc (psia)	232	225	223	228	220	215	212	217	233	225	225	226	220	214	211	216
MR	5.7	5.7	5.7	5.7	5.4	5.4	5.4	5.4	5.7	5.7	5.7	5.7	5.4	5.4	5.4	5.4
Ac/At	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
CEA/CETPC RESULTS:																
Pc,ns (psia)	227	220	219	224	215	210	208	212	228	220	220	222	215	209	207	211
c*, theo (ft/s)	7661	7658	7657	7658	7748	7746	7745	7746	7660	7656	7655	7656	7746	7744	7742	7744
g	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Mc	0.144	0.144	0.144	0.144	0.144	0,144	0.144	0.144	0.144	0.144	0.144	0.144	0.144	0.144	0.144	0.144
T,gas (R)	6014	6007	6005	6010	5940	5936	5933	5936	6014	6006	6005	6007	5938	5933	5931	5935
Calculations:																
c,actual (ft/s)*	*7509*	*7277*	*7244*	*7410*	*7420*	*7247*	*7178*	*7316*	*7408*	*7148*	*7148*	*7213*	*7288*	*7085*	*7017*	*7153*
C*,efficiency %	98	95	95	97	96	94	93	94	97	93	93	94	94	91	91	92

K.1 Performance Calculations

For the hot-fires, performance data included MR, actual C^* values, and C^* efficiencies.

K.1.1 Mixture Ratio

For each thruster,

$$\mathrm{MR} = \frac{\dot{m}_o}{\dot{m}_f} , \tag{10}$$

where

$\dot{m}_o$ = oxidizer flow rate, lb_m/sec

$\dot{m}_f$ = fuel flow rate, lb_m/sec.

Example (GRUN0037):

For thruster No. 1: $\dot{m}_o = 1.48\ \mathrm{lb_m/sec}$ and $\dot{m}_f = 0.26\ \mathrm{lb_m/sec}$

Solving equation (12)

$$MR = \frac{1.48}{0.26} = 5.7\ .$$

K.1.2 Actual *C** and *C** Efficiency

*C** is defined as the characteristic velocity of the resulting combustion gases:

$$C^*_{\text{actual}} = \frac{P_{c,ns} \cdot A_t \cdot g_c}{\dot{m}_o + \dot{m}_f}\ , \tag{11}$$

where

$P_{c,ns}$ = nozzle stagnation pressure (psia)

A_t = chamber throat area (in.^{2})

g_c = gravitational constant = 32.2 $\mathrm{lb_m\ ft/lb_f\ s^2}$.

In order to calculate the actual C^* correctly, $P_{c,ns}$ was determined. This stagnation pressure would be less than the P_c measured up near the injector due to Rayleigh losses from the injector to the nozzle stagnation point (where the chamber contour starts to converge). In addition, there was a theoretical C^* value that was associated with specific propellant combinations, P_c's and MR's. This theoretical C^* was the velocity that should result if the design and operation were perfect, and the combustion gases experienced no energy losses (such as Rayleigh losses or heat losses to the coolant). By comparing the theoretical value to the actual value, the C^* efficiency was determined to provide a relative idea of each thruster's performance.

A rocket performance code called "CETPC" was used to determine $P_{c,ns}$ and the theoretical C* values. CETPC is also known as ODETRAN and CEA—they are all basically the same FORTRAN code (developed by Gordon and McBride at NASA's Lewis Research Center). A computer code called MIPROPS was used to find the specific thermodynamic properties of oxygen and hydrogen.

Inputs to CETPC include:

- LOX and fuel inlet enthalpies
- LOX and fuel inlet temperatures
- P_c (psia) as measured at the injector end
- MR
- A_c/A_t = chamber's contraction ratio
- A_c = chamber area at the injector end
- A_t = chamber throat area.

Example (GRUN0037):

Thruster No. 1:

Inlet enthalpies have to be input in cal/mol:

LOX mfd. pressure = 309 psia
LOX mfd temp. = –248 °F
$h_{O_2} = -36.2\ \mathrm{BTU/lb_m}$.

Convert this value to cal/mol:

$$h_{o_2} = -36.2 \frac{\mathrm{BTU}}{\mathrm{lb_m}} \left(\frac{2.23\ \mathrm{J/g}}{\mathrm{BTU/lb_m}} \right) \left(\frac{32\,\mathrm{g}}{\mathrm{mol}} \right) \left(\frac{252.2\,\mathrm{cal}}{1055\,\mathrm{J}} \right) = -642.45\ \mathrm{cal/mol} \ .$$

Subtract the enthalpy for O_2 at standard conditions (14.7 psia, 78 °F)

$h_{o_2,\mathrm{std}} = 2070.5$ cal/mol

$h_o = -642.45 - 2070.5 = -2713$ cal/mol.

LOX inlet temperature must be input in K: $T_o = (-248 + 460)/1.8 = 117.8$ K.

Fuel mfd. pressure = 322 psia
Fuel mfd. temperature = 18 °F
From MIPROPS: $h_{H_2} = 1{,}587\ \mathrm{BTU/lb_m}$.

Convert this value to cal/mol :

$$h_{H_2} = 1587 \ \frac{\mathrm{BTU}}{\mathrm{lb_m}} \left(\frac{2.23\ \mathrm{J/g}}{\mathrm{BTU/lb_m}} \right) \left(\frac{2\,\mathrm{g}}{\mathrm{mol}} \right) \left(\frac{252.2\,\mathrm{cal}}{1055\,\mathrm{J}} \right) = 1760.3\ \mathrm{cal/mol} \ .$$

Subtract the enthalpy for H_2 at standard conditions:

$$h_{H_2,\text{std}} = 2{,}024.3 \text{ cal/mol}$$

$$h_f = 1{,}760 - 2{,}024.3 = -263.99 \text{ cal/mol} \ .$$

Fuel inlet temperature must be input in K: $T_f = (18+460)/1.8 = 265.55$ K.

The rectangular cross-sectioned chamber measured:

At the injector end: 5.015 in. ×1.5 in.
At the throat: 4.995 in. × 0.357 in.
$A_c = (5.015)(1.5) = 7.5225 \text{ in.}^2$
$A_t = (4.995)(0.357) = 1.7832 \text{ in.}^2$

$$\frac{A_c}{A_t} = \frac{7.52}{1.78} = 4.2 \ .$$

Based on the output from CETPC, when the chamber contracts, ($A_c/A_t = 4.2$, $M = 0.144$) $P_{\text{inj}}/P = 1.0234$, where $P_{\text{inj}} = P_c$ measured at the injector end and $P = P_{c,ns}$.

So,

$$P_{c,ns} = \frac{232 \text{ psia}}{1.0234} = 227 \text{ psia} \ .$$

Solving equation (11)

$$\therefore C^*_{\text{actual}} = \frac{(227 \text{ lb}_\text{f} / \text{in.}^2)(1.78 \text{ in.}^2)(32.2 \text{ lb}_\text{m} \cdot \text{ft} / \text{lb}_\text{f} \cdot \text{s}^2)}{(1.48 + 0.26)\text{lb}_\text{m} / \text{sec}} = 7509 \text{ ft / sec} \ .$$

From CETPC,

$$C^*_{\text{theo}} = 7661 \text{ ft / sec}. \text{ As a result,}$$

$$C^*_{\text{efficiency}} = \frac{C^*_{\text{actual}}}{C^*_{\text{theo}}} = \frac{7509}{7661} = 0.98 \ .$$

Output from CETPC is shown in table 14.

Table 14. Output from CETPC program.

```
            THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM
          COMPOSITION DURING EXPANSION FROM FINITE AREA COMBUSTOR

PINJ =    232.0 PSIA
AC/AT =  4.2000
CASE NO.       1

        CHEMICAL FORMULA               WT FRACTION    ENERGY   STATE   TEMP
                                        (SEE NOTE)    CAL/MOL         DEG K
FUEL     H  2.00000                      1.000000     -263.000   L     265.50
OXIDANT O   2.00000                      1.000000    -2713.000   L     117.60

O/F= 5.7000   PERCENT FUEL=  14.9254   EQUIVALENCE RATIO= 1.3924  PHI=1.3924

                INJECTOR INF CHAM   THROAT CN RATIO
PINJ/P            1.0000   1.0115   1.7499     1.0234
PINF/P            .98864   1.0000   1.7300   1.0117
P, ATM            15.787   15.607   9.0214   15.426
T, DEG K         3346.63  3345.24  3179.10     3341.63
RHO, G/CC       7.2715-4 7.1910-4 4.4315-4 7.1172-4
H, CAL/G         -91.602  -91.602  -370.67  -97.736
U, CAL/G         -617.36  -617.21  -863.67  -622.63
G, CAL/G        -15601.8 -15601.3 -15110.1 -15590.7
S, CAL/(G)(K)     4.6346   4.6364   4.6364   4.6364

M, MOL WT         12.649   12.648   12.815   12.651
(DLV/DLP)T      -1.03540 -1.03548 -1.02858 -1.03533
(DLV/DLT)P        1.6496   1.6512   1.5515   1.6491
CP, CAL/(G)(K)    2.8004   2.8059   2.5692   2.8013
GAMMA (S)         1.1328   1.1328   1.1321     1.1327
SON VEL,M/SEC     1578.6   1578.3   1528.2   1577.2
MACH NUMBER         .000     .000    1.000       .144

PERFORMANCE PARAMETERS

AE/AT                               1.0000     4.2000
CSTAR, FT/SEC                         7661       7661
CF                                    .654      .097
IVAC,LB-SEC/LB                       293.5   1011.6
ISP, LB-SEC/LB                       155.8     23.1


GR37TH1.OUT
```

Note: Theoretical C^* was calculated in CETPC relative to theoretical T_{gas}, but some heat was actually lost to the coolant in the combustion chamber—making the actual T_{gas} lower than the theoretical value. To adjust T_{gas} relative to the heat picked up by the coolant:

$$C^*_{\text{theo}} = \frac{\sqrt{g_c \gamma \mathbf{R} T_{c,ns}}}{\gamma \sqrt{\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}}} \qquad Tc,ns = T_{gas} \text{ at nozzle stag. point} \qquad (12)$$

$$\dot{Q} = (\dot{m} C_p \Delta T)_{H_2O} \qquad \text{(heat gained by coolant = heat lost from gas)} \qquad (13)$$

$$\Delta T_{\text{gas}} = \frac{\dot{Q}}{(\dot{m}_o + \dot{m}_f)C_{p,\text{gas}}} \tag{14}$$

$$\text{Actual } T_{\text{gas}} = \text{theo } T_{\text{gas}} - \Delta T_{\text{gas}} \tag{15}$$

$$\text{Corrected } C^*_{\text{theo}} = \frac{C^*_{\text{theo}}\sqrt{\text{actual } T_{\text{gas}} - \Delta T_{\text{gas}}}}{\sqrt{\text{actual } T_{\text{gas}}}} \; . \tag{16}$$

However, ΔT_{H_2O} is the temperature rise by the coolant in each thruster between the injector and the nozzle stagnation point. In the LASRE program, only the total ΔT picked up by the coolant through the thrusters and the fences/ramps was available. The ΔT up to each thruster's nozzle stagnation point would be significantly smaller, creating little effect on the theoretical C^* value. Therefore, corrections for heat loss were not performed for this program. Actually, in the LASRE program, the C^* efficiencies were only meant for comparisons between thrusters and hot-fire tests, not true performance evaluation, so this correction was not important.

APPENDIX L—Flight Configuration Test Results

Figure 37 shows the transient data for the LOX and fuel systems. Transient plots compare GR'35: ground cold flow prior to ground hot-fire; GR'36: first ground hot-fire; GR'37: second ground hot-fire; and FLT'49: flight cold flow. Data shown for all tests starts at ≈5 sec prior to "SS." Flight configuration testing produced results similar to ground tests.

Transient data are shown for the water system (fig. 38) and engine system (figs. 39 and 40). The water system, engine and TEA-TEB systems responded appropriately and consistently for cold flows and hot-fires in the ground and flight configurations.

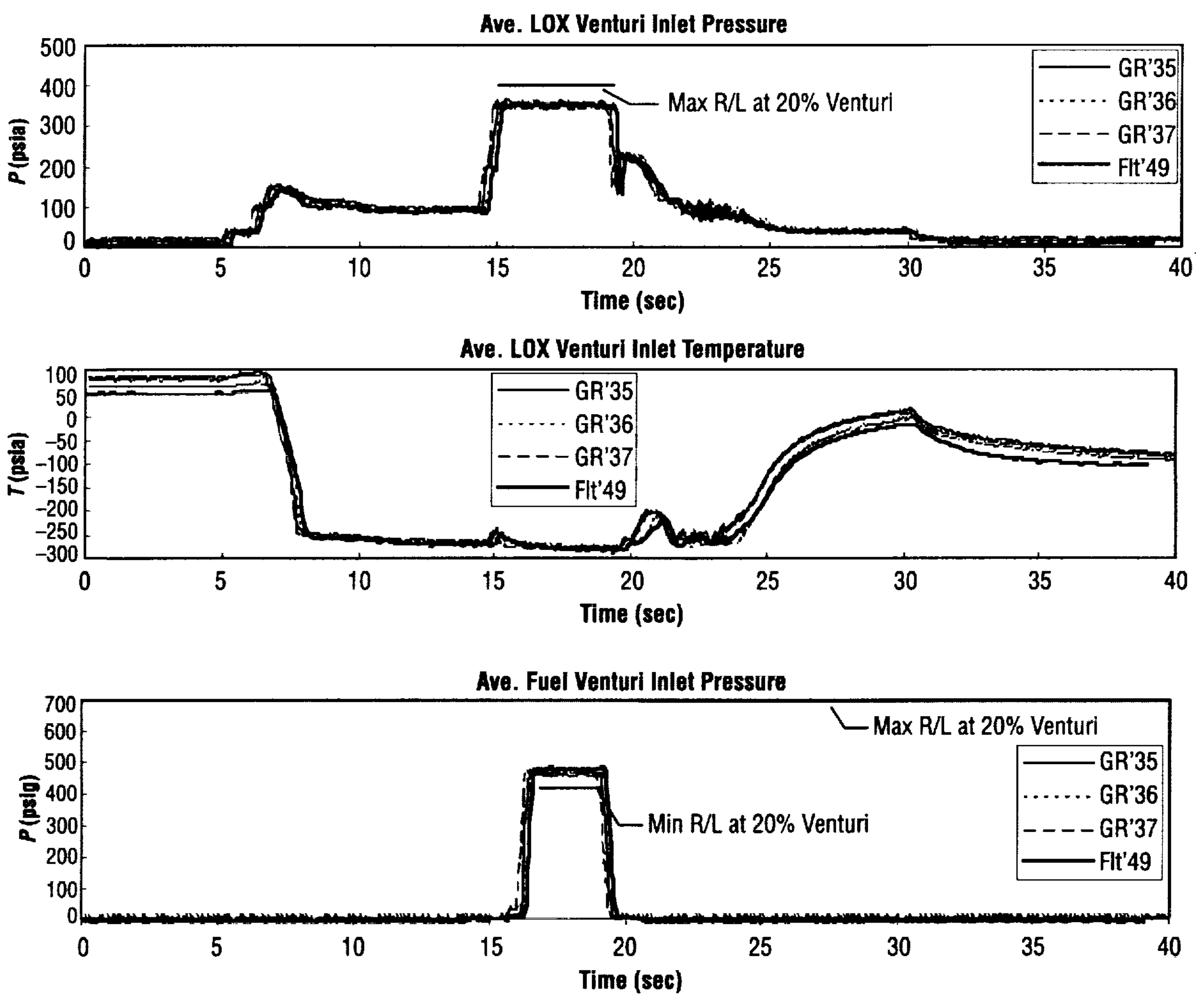


Figure 37. LOX and fuel—transient data.

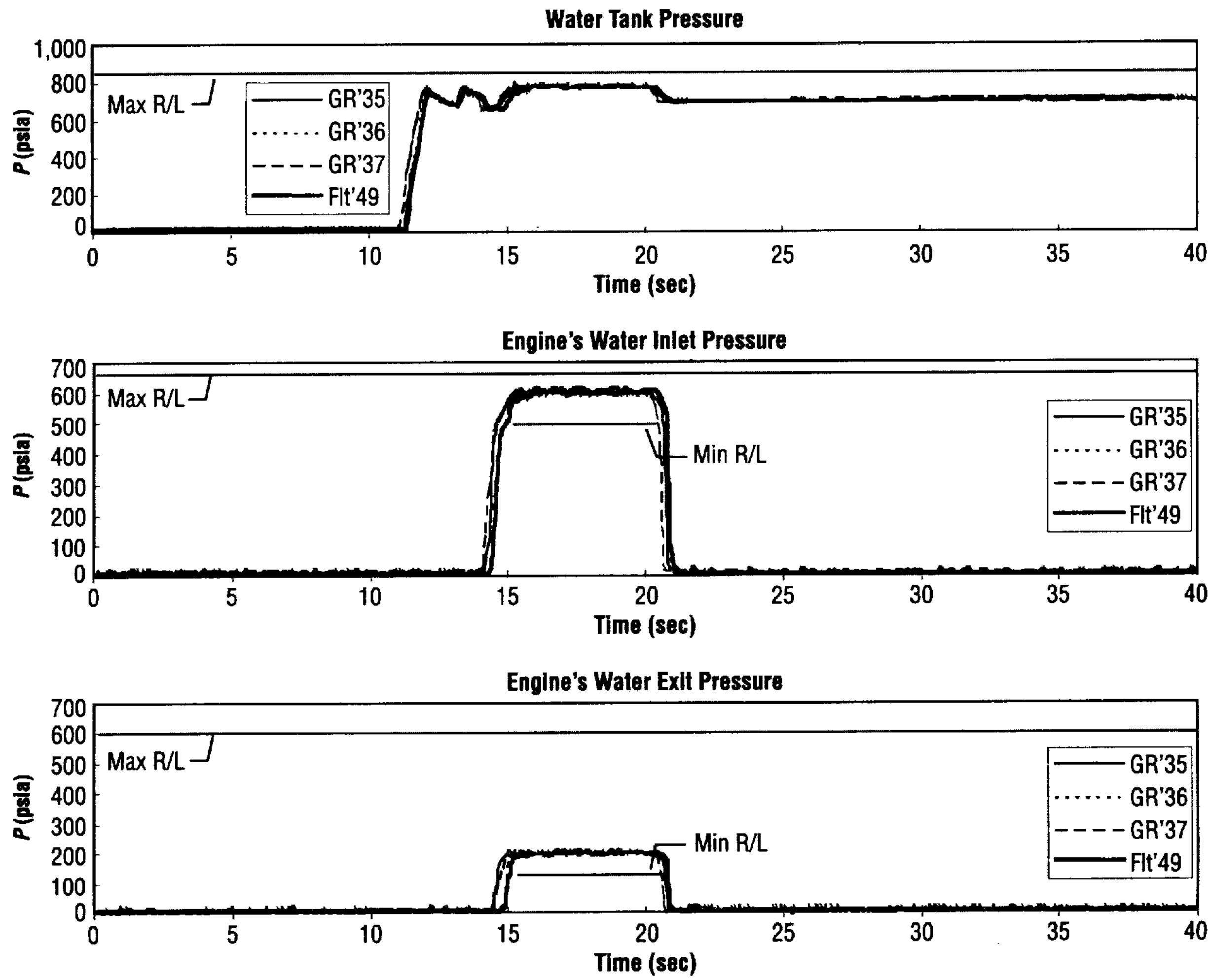


Figure 38. Water system—transient data.

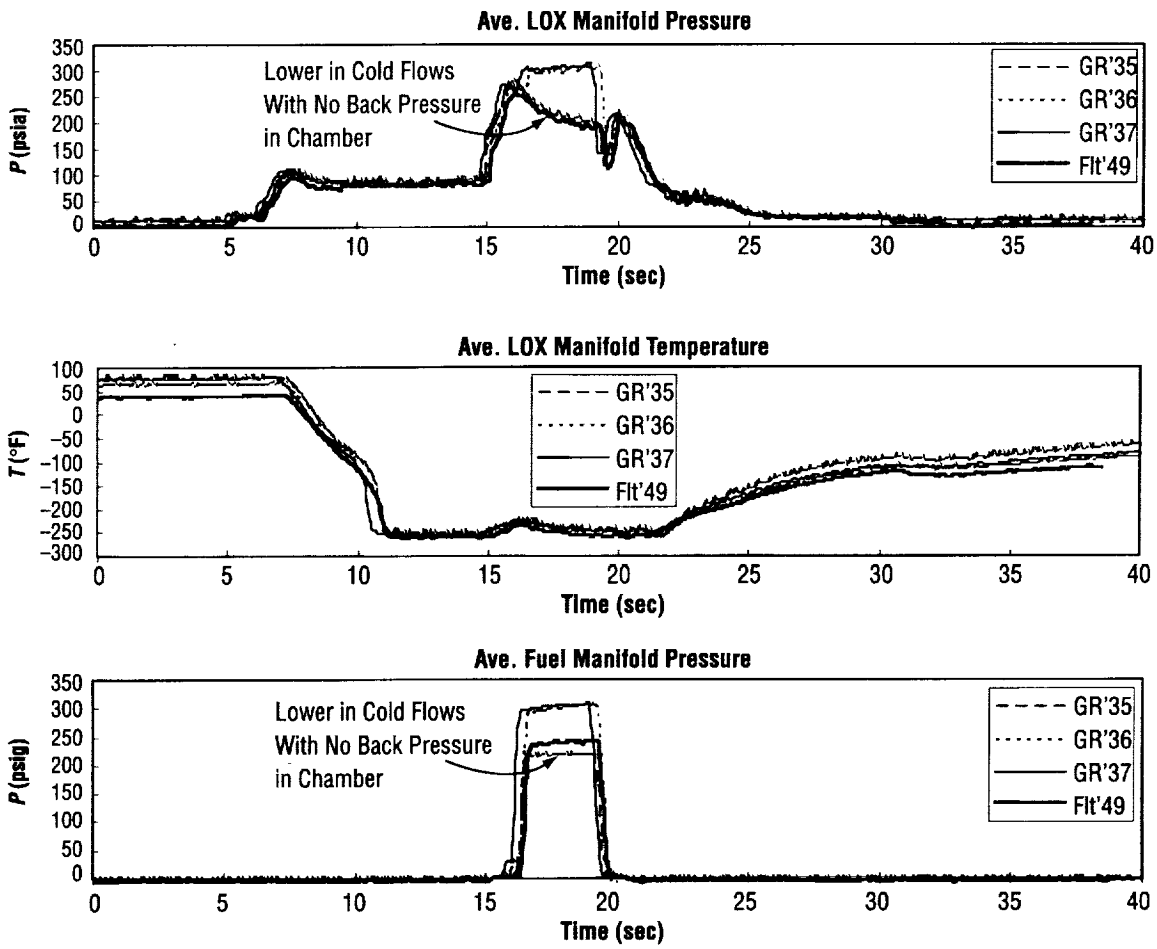
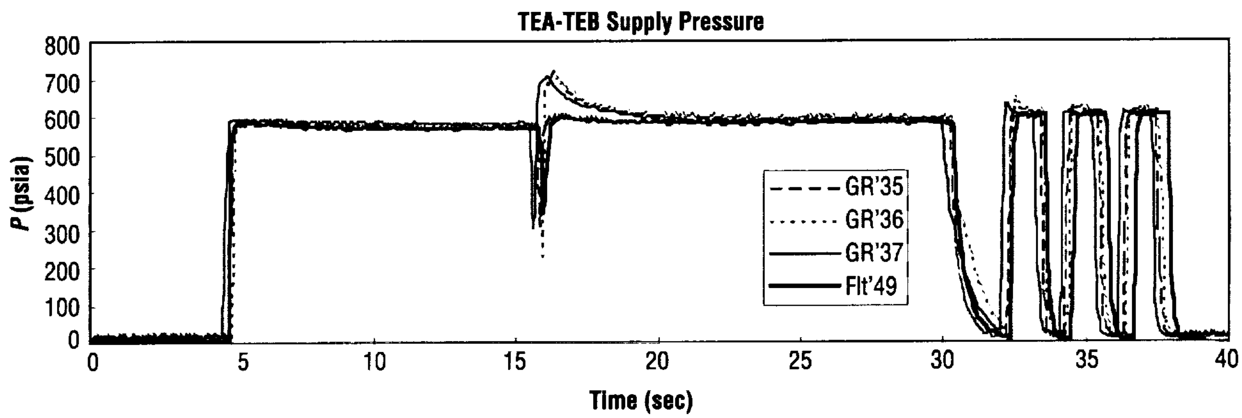


Figure 39. Engine—transient data.



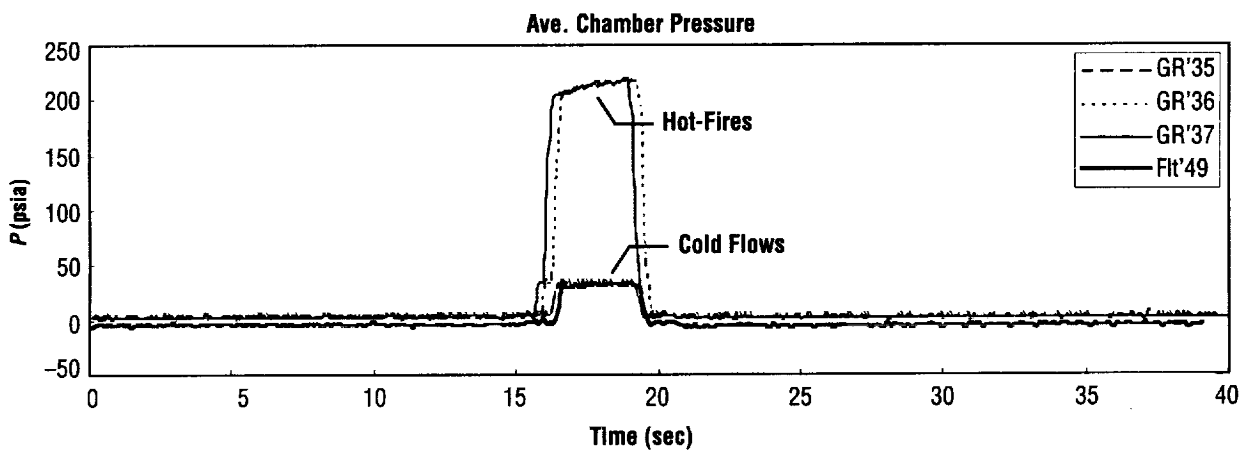


Figure 39. Engine—transient data (Continued).

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13. ABSTRACT *(Maximum 200 words)*

The Linear Aerospike SR–71 Experiment (LASRE) was performed in support of the Reusable Launch Vehicle (RLV) program to help develop a linear aerospike engine. The objective of this program was to operate a small aerospike engine at various speeds and altitudes to determine how slipstreams affect the engine's performance. The joint program between government and industry included NASA's Dryden Flight Research Center, The Air Force's Phillips Laboratory, NASA's Marshall Space Flight Center, Lockheed Martin Skunkworks, Lockheed-Martin Astronautics, and Rocketdyne Division of Boeing North American. Ground testing of the LASRE engine produced two successful hot-fire tests, along with numerous cold flows to verify sequencing and operation before mounting the assembly on the SR–71. Once installed on the aircraft, flight testing performed several cold flows on the engine system at altitudes ranging from 30,000 to 50,000 feet and Mach numbers ranging from 0.9 to 1.5. The program was terminated before conducting hot-fires in flight because excessive leaks in the propellant supply systems could not be fixed to meet required safety levels without significant program cost and schedule impacts.

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