NASA Technical Memorandum 107469
AIAA–97–2976

Performance Tests of a Liquid Hydrogen Propellant Densification Ground System for the X33/RLV

Thomas M. Tomsik
Lewis Research Center
Cleveland, Ohio

Prepared for the
33rd Joint Propulsion Conference & Exhibit
cosponsored by AIAA, ASME, SAE, and ASEE
Seattle, Washington, July 6–9, 1997

National Aeronautics and
Space Administration

PERFORMANCE TESTS OF A LIQUID HYDROGEN PROPELLANT DENSIFICATION GROUND SUPPORT SYSTEM FOR THE X33/RLV

Thomas M. Tomsik
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

Abstract

A concept for improving the performance of propulsion systems in expendable and single-stage-to-orbit (SSTO) launch vehicles much like the X33/RLV has been identified. The approach is to utilize densified cryogenic liquid hydrogen (LH_2) and liquid oxygen (LOX) propellants to fuel the propulsion stage. The primary benefit for using this relatively high specific impulse densified propellant mixture is the subsequent reduction of the launch vehicle gross lift-off weight.

Production of densified propellants however requires specialized equipment to actively subcool both the liquid oxygen and liquid hydrogen to temperatures below their normal boiling point. A propellant densification unit based on an external thermodynamic vent principle which operates at subatmospheric pressure and supercold temperatures provides a means for the LH_2 and LOX densification process to occur. To demonstrate the production concept for the densification of the liquid hydrogen propellant, a system comprised of a multistage gaseous hydrogen compressor, LH_2 recirculation pumps and a cryogenic LH_2 heat exchanger was designed, built and tested at the NASA Lewis Research Center (LeRC). This paper presents the design configuration of the LH_2 propellant densification production hardware, analytical details and results of performance testing conducted with the hydrogen densifier Ground Support Equipment (GSE).

Nomenclature

C_{m2}	meridional fluid velocity
GHP	gas horsepower
GLOW	gross lift-off weight
GSE	ground support equipment
h	enthalpy
H	head
Isp_v	vacuum specific impulse
LeRC	Lewis Research Center
LH_2	liquid hydrogen
LN_2	liquid nitrogen
LOX	liquid oxygen
M	mass
$\dot{m}$	mass flow rate
MSFC	Marshall Space Flight Center
NBP	normal boiling point
PD	propellant densification
PLC	programmable logic controller
Q_{env}	environmental heat transfer rate
RLV	reusable launch vehicle
SSTO	single-stage-to-orbit
t	time
TP	triple point
U	internal energy
U_2	impeller tip speed

V volume
VJ vacuum-jacketed

Greek

Ψ head coefficient
Φ flow coefficient
η efficiency
ρ density

Subscripts

L liquid
R recirculating
V vapor

Introduction

The desire to increase the payload capabilities and performance of SSTO reusable launch vehicles (RLV) is driven by constantly evolving mission requirements. Construction of the International Space Station Freedom, Mission to Planet Earth, a return to the Moon and planetary exploration of Mars and far beyond demonstrate the variety of potential future mission profiles. In support of these missions, the next generation RLV demands several technological improvements in order to achieve a lower cost and more reliable access to space. Advancements in higher performance engines, light weight composite structures, propellant tanks constructed of light-composite materials including graphite-epoxy and aluminum-lithium, durable thermal protection subsystems and electromagnetic actuators replacing hydraulics all constitute improvements to the RLV technology cache. One technology area that has not been as aggressively developed is densification of cryogenic liquid propellants, even though the performance gains in an RLV application exceed those improvements previously cited.

Propellant densification (PD) by itself is not a new technology approach considering the former development of slush hydrogen for the National Aerospace Plane[1-3] and other programs. The operational problems associated with the solid-liquid propellant mixture have however deterred wide-spread acceptance of the fuel. Production of densified propellant at conditions above the triple-point (TP) temperature is a much simpler process, and a less costly technique without the vehicle operational complexities of a slush mixture. A continuous process for subcooling LH_2 propellant above the TP, without the generators, mixers, two-phase pumps, etc., that are commonly associated with the large-scale slush hydrogen production facility, has significant operations and cost advantages in the RLV application. The continuous PD concept developed in this work is a ground support unit comprised of a pump, compressor, and heat exchanger for LH_2 propellant subcooling, and an integrated recirculation system for the launch vehicle propellant tank.

Cryogenic propellants at temperatures below their NBP have a higher bulk density and reduced vapor pressure. The greater density fluid permits the use of smaller sized and consequently lighter launch vehicle propellant tanks. The lower vapor pressure propellant allows the vehicle tank design and operating pressure to be reduced, permitting the use of thinner walled vessels. The combination of these effects contributes to a significant improvement in the vehicle gross lift-off weight (GLOW). Study estimates[4,5] for RLV's using densified propellants indicate performance benefits ranging from 15 to 32 percent reduction in vehicle GLOW compared to the vehicle fueled with NBP LH_2/LOX propellants. Because of this significant RLV performance and cost advantage by vehicle weight reduction with the use of subcooled cryogens, a propellant densification technology demonstration program[6] was conducted by the NASA LeRC and Rockwell Space Systems Division (RSSD). The PD work completed during this effort was funded by Marshall Space Flight Center (MSFC) under NASA Contract NCC8-79.

This paper describes the results of the Phase I liquid hydrogen PD experimental program conducted at the LeRC. A subscale LH_2 propellant densification system, sized for a 20 000 gal LH_2 tank, was designed, constructed, operationally checked-out with liquid nitrogen (LN_2) and functionally tested using liquid hydrogen propellant by LeRC. Performance tests were conducted at the K-Site Cryogenic Propellant Tank Facility located at the NASA LeRC Plum

Brook Station. Liquid hydrogen densification test results to be reported include data for GSE unit mass flow rates, subcooled LH_2 temperatures for the heat exchanger system and compressor operating conditions. Also presented here is background information on the thermodynamic process for subcooling the LH_2 propellant, a description of the GSE hardware configuration and K-Site test facility, details of GSE test procedures, operational problems encountered with the GSE and analytical comparisons with densification system performance models.

Background

The ideal rocket engine propellant is characterized as one with a high specific impulse (Isp_v), high density and low vapor pressure. LH_2/LOX is one of the highest performance propellants with a nominal Isp_v of 450 sec. The problem with LH_2 stored at the NBP at standard conditions is its relatively low density and high vapor pressure. Liquid hydrogen has a density of 4.4 lb/ft^3 at its NBP. Subcooling LH_2 to a temperature of 28 °R increases the density to 4.7 lb/ft^3 corresponding to a 7 percent density gain. The vapor pressure of LH_2 at these conditions is reduced from 14.7 to 2.6 psia representing an 82 percent change. Figure 1 shows the LH_2 density and vapor pressure improvement as the temperature is reduced. The higher density propellant requires less tank volume, reducing tank size and mass. Due to the reduced vapor pressure, the subcooled propellant needs a lower tank operating pressure while still maintaining the net-positive suction head requirements for the pump fed engine system.

The densification of liquid hydrogen is based on the well characterized thermodynamic vent principle. The basic densification GSE unit itself, integrated with an RLV propellant tank (Fig. 2), consists of a LH_2 recirculation pump, LH_2 heat exchanger and gaseous hydrogen (gH_2) compressor. The production of supercold LH_2 temperatures is accomplished by withdrawing saturated liquid hydrogen off the top of the thermally stratified RLV tank through a collector manifold, circulating it through the heat exchanger of the ground cooling unit, and returning the subcooled propellant from the GSE to the bottom of the RLV tank. Subatmospheric pressure boiling at 1.2 psia provides the 25.4 °R thermal heat sink required to condition the propellant in the LH_2 heat exchanger.

In order to maintain the propellant tank at thermally stratified conditions, a very important aspect in the overall performance of the densification process in terms of the time required to accomplish the desired densification, warm saturated liquid is withdrawn off the top using a collector manifold and the subcooled propellant from the GSE is returned to the bottom. The tubes of the GSE heat exchanger are submerged in a low temperature LH_2 boiling bath maintained at subatmospheric pressure. To generate subcooled LH_2 at 27 °R, the heat exchanger bath operating filled with LH_2 is reduced to a pressure of 1.2 psia causing the liquid to boil at 25.4 °R. This low temperature boiling provides the thermal heat sink required to condition the propellant. The inlet LH_2 stream is gradually subcooled through the tubes of the heat exchanger and exits at the desired 27 °R outlet temperature. The gH_2 compressor maintains the heat exchanger ullage pressure constant at 1.2 psia and rejects the boiled-off gH_2 saturated vapor to the atmospheric pressure vent.

Test Apparatus and Procedure

K-Site Test Facility

The experimental testing for the LH_2 densification program was performed at the K-Site Cryogenic Propellant Tank Facility located at the NASA LeRC Plum Brook Station. The K-Site facility (Fig. 3) contains the main test building housing a 25 ft vacuum chamber, a remotely located control room, cryogenic liquid and gas storage areas, and equipment for slush hydrogen production. The LH_2 propellant densification GSE was installed outdoors (Fig. 4) on an existing concrete slab located near the vacuum pump building adjacent to a reinforced blast wall. The PD system components are assembled on a welded I-beam structure, 36 ft long and 8 ft 6 in. wide.

The facility liquid hydrogen equipment for the PD tests consist of two 13 000 gal roadable dewars, vacuum jacketed transfer lines and a dewar vent system. A plan schematic of the LH_2 GSE fluid handling system is shown in Fig. 5. The H24 rail station dewar supplies LH_2 to the GSE pumps and heat exchanger. Subcooled propellant from the GSE flows to the H25 receiver dewar for storage. Vent valves on both dewars are routed to the 6 in. south burn-off and flared with a natural gas pilot. The discharge line from the gH_2 compressor ties into a second 6-in. vent line which also terminates at the south burn-off flare stack. Foam insulated lines connect the facility vacuum jacketed lines leading to the GSE skid through mating bayonets with short VJ extensions. One remote operated valve (V210) is installed in the skid supply piping to allow the back-transfer of LH_2 from the roadable H25 dewar to the rail station H24 dewar to bypass the densification test rig.

Gaseous helium (gHe) used for purging is supplied to the GSE at 45 psig from the K-Site gHe bottle farm and tuber systems. Gaseous nitrogen is provided to the skid at 90 psig for valve operator pressure. Liquid nitrogen used during cold shock and densification checkout tests was fed from a separate LN_2 dewar temporarily placed adjacent to the skid. A portable 400 KVA 7200/480 V transformer provided 480 and 208V three phase electrical power to motors on the LH_2 recirc pumps, gH_2 compressor and its cooling system pump and fan.

Propellant Densification GSE Hardware

The propellant densification GSE is designed to subcool 2.0 lb_m/sec of saturated LH_2 propellant. The heat exchanger duty rating is 60 Btu/sec with flowing LH_2 at maximum inlet conditions of 40 psia and 43 °R. The subcooled product design outlet temperature from the densifier unit exchanger is 27 °R. Table I lists the design parameters for the test bed GSE. The major hardware for producing the densified propellant (Fig. 6) consists of two LH_2 recirculation pumps mounted inside a dewar, a cryogenic LH_2 heat exchanger and a gH_2 centrifugal compressor. A GSE system flow schematic (Fig. 7) configured for the K-Site LH_2 densification tests shows the rig to be set-up for once-through flow testing where LH_2 flows from dewar H24 to H25. The primary test objective in this series was to demonstrate heat exchanger-compressor performance and the production of 27 °R subcooled propellant.

Recirculation Pumps

For K-Site densification test operations, LH_2 from the H24 rail station dewar, operating self-pressurized at 40 psia, supplies warm liquid to the GSE system. With valve V210 closed, LH_2 flows through valve PV-1 to the recirculation pump inlets. The recirculation pumps (Fig. 8) are arranged in parallel and capable of flowing 200 gpm through the 3 in. Sch 10 vacuum jacketed (VJ) piping system. They develop a 5 psid differential pressure rise at a design point speed of 7400 rpm. The submersible pumps operate in a cold-guard dewar (Fig. 9) filled with NBP LH_2 to control environmental heat leak and provide motor cooling. The dewar bath level is controlled by sensing liquid level with silicon diodes and adding make-up LH_2 through valve PV-2.

Located just upstream of the recirculation pumps is a 1 in. LH_2 VJ supply line. This makeup flow stream would maintain the X33 propellant tank level constant as fluid bulk density is reduced during a 2 hr densification process. The makeup flow rate, nominally ranging from 13 to 24 gpm, would be monitored by a venturi flow meter and controlled by valve PCV-1. The control valve would sense tank level by an input signal from a liquid-level capacitance probe mounted near the top of the X33 vehicles' propellant tank. Due to the single pass operation of the GSE for the demonstration testing at K-Site, this part of the system was not operated.

Heat Exchanger

The pump discharge stream flows through valve PV-4 and enters the LH_2 heat exchanger. Inlet conditions are 40 psia and 36 to 44 °R depending on the H24 supply dewar outlet liquid temperature. The inlet flow rate to the heat exchanger is measured with a venturi flow meter. Liquid hydrogen flows through the heat exchanger tube bundle where the fluid is progressively cooled to the 27 °R product outlet temperature. Six silicone diodes mounted on the axis of a single heat exchanger tube provide wall temperature gradient data. The subcooled fluid exits the heat exchanger, flows through valve PCV-4 and is directed to the H25 roadable dewar for storage. The heat exchanger bath level is maintained constant by sensing bath liquid level with silicon diodes mounted on a probe. Level control valve PCV-3 opens when the input signal from a low-level control diode detects the level has dropped below its fixed position.

The LH_2 heat exchanger assembly (Fig. 10) is a single-pass shell and tube design constructed of a manifolded aluminum tube bundle, a 304SS inner vessel and a carbon steel outer vessel which forms a vacuum jacket for the inner assembly. There are 150 extruded aluminum tubes with machined fins providing nearly 600 ft^2 of effective surface area. This particular design permits the extremely close exit-end approach temperatures necessary for subcooling the propellant to within 1 °R of the boiling LH_2 bath. Heat rejection from the exchanger produces a design boil-off rate of 0.4 lb_m/sec of saturated gH_2 vapor. Shellside ullage conditions are maintained at 1.2 psia and 26 °R.

Hydrogen Compressor

The supercold vent gas from the heat exchanger flows through isolation valve BV-1 to the inlet of the hydrogen compressor system. The four-stage centrifugal compressor (Fig. 11) is designed to compress the cold inlet gas from 26 °R and 1.2 psia to a discharge pressure of 15.6 psia. To maintain the heat exchanger bath pressure constant at 1.2 psia, compressor speed is either manually or automatically adjusted by a single 200 hp variable frequency drive controller (VFD). Compressor speed compensation with the VFD provides a method to control the heat exchanger bath pressure constant at off-design vent gas flow rates resulting from changes in heat exchanger inlet LH_2 temperature and mass flow rate.

Each compressor stage operates at the same rotational design point speed of 22 000 rpm with the common VFD. The compressor stages are driven by individual high-speed AC induction motors each rated at 460 V, 3 phase, 60 Hz and 40 hp. The drive motors housings are cooled with a recirculating propylene-glycol coolant loop. The fourth compressor stage discharges 1180 ACFM of gH_2 at 15.6 psia and 128 °R into a 4 in. vent line. From stage four, the gH_2 vent flows through shut-off valve BV-3 and discharges into the facility vent system where the gas is flared and vented to atmosphere. The total compressor exhaust flow rate is measured by a turbine flow meter for monitoring low-flow conditions necessary to control compressor surge instability. Gas-bypass valve BV-2 opens manually or automatically at the onset of surge detection. Surge is controlled by injecting recirculation gas into the heat exchanger LH_2 bath where the gas cools, vaporizes additional liquid, dissipates heat of compression and recycles to the inlet of the first stage.

Instrumentation

Temperature sensors used on the GSE system were predominantly silicone diode (SiD) type probes with an accuracy of ±0.5 °R. A total of 43 installed SiDs provided temperature data for the LH_2 recirculation, heat exchanger and gH_2 compressor systems. Fifteen capacitive type pressure transducers installed on the GSE indicated LH_2 and gH_2 system pressures ranging from less than 2 to 50 psia. Differential pressure transducers sensing ΔP for each of the four venturi flow meters provided information for calculating GSE mass flow rates. The gH_2 compressor discharge flow rate was measured with a 2 percent accurate 6 in. turbine flow meter.

Data Acquisition

The data acquisition system (DAQ) used during PD testing at K-Site was the ESCORT D program. ESCORT D was set up to provide real-time monitoring of 70 GSE and facility data channels. Data was recorded at a nominal rate of 1 scan/sec/channel, simultaneous. The DAQ system included a variety of signal conditioners and analog filters to accommodate the different sensor types. A dedicated microVAX computer located in the K-Site control building was linked to the NASA LeRC VAX mainframe computer system. The microVAX was used for temporary data storage prior to data transmission to LeRC for post-run analysis. No averaging or smoothing of the raw data was performed with the PD data-sets reported.

Test Procedures

Hydrogen densification GSE test procedures involved several operations. Pretest activities included establishing K-Site facility systems, GSE vacuum purging, gHe inerting, system chill down of LH_2 transfer lines, and LH_2 fill of the heat exchanger bath and pump dewar. Test and post-test activities involved verification of valve settings, actual GSE unit startup of the pumps and gH_2 compressor, data recording, GSE shutdown and facility safeing and post-run cleanup. Remote operation of the test rig was conducted by personnel stationed inside the K-Site facility Control room using a control panel (Fig. 12) and a programmable logic controller (PLC) interface designed for the GSE. Remote video displays provided a visual observation of the GSE during testing.

Following completion of the pretest operations, a typical LH_2 densification test run procedure was to pressurize the H24 rail station supply dewar to 40 psia. The H25 roadable dewar would be set vented to slightly above atmospheric pressure. The heat exchanger bath (PCV-3) and pump dewar (PV-2) level control valves were placed in their automatic control modes. The desired mass flow rate through the densifier was established by opening and then adjusting the PCV-4 control valve and monitoring the heat exchanger inlet mass flow with a venturi flow meter. With the flow rate through the heat exchanger stabile, the compressor glycol coolant system pump and heat exchanger fan were started. The compressor acceleration rate was preprogrammed for a 2 200 rpm/min ramp. The desired compressor set-point speed was initially programmed into the PLC, typically 8 000 rpm for the LN_2 tests and 22 000 rpm for the LH_2 testing. The compressor system was started in VFD manual speed control by the power-on button. The DAQ system was started and key variables including LH_2 flow rate, compressor speed, and heat exchanger bath pressure would be closely monitored. The densification system was operated until a steady-state condition was reached, the rig was manually shut-down by the operator, or until the PLC detected an abort condition and triggered a fault-shutdown of the GSE.

Results and Discussion

A series of LN_2 system cold-shock, proof-pressure tests, gHe mass-spec leak checks and component functional checkouts were initially run on the GSE. Following the subsystem checkouts, three LN_2 densification tests were conducted. Liquid hydrogen densification testing began at K-Site in mid-December 1996 with a total of four LH_2 densification tests performed. Table II provides a run summary of the experimental conditions for the seven densification tests completed during this phase of the program. A more detailed review of the densification test results including mass balances, and system temperatures and pressures is presented in the sections below.

Liquid Nitrogen Densification Results

The objectives of the LN_2 densification tests were to evaluate the performance of the GSE as a system and gain operating experience with the equipment before proceeding with the hydrogen testing. Although the densifier was designed to process LH_2, analysis of the equipment performance specifications resulted in the following target run conditions for the LN_2 densification trials: 9.0 lb_m/sec recirc mass flow rate, 3.0 psia heat exchanger bath pressure, and 8 000 rpm compressor operating speed. The first two attempted LN_2 densification runs were affected by high frequency electrical noise problems generated by the compressor AC drive motors. The other problems encountered were maintaining a high enough LN_2 recirc flow rate through the rig due to mechanical difficulties with the LH_2 recirc pumps and an excessive back pressure caused by the K-Site facility VJ piping downstream of the GSE. Liquid nitrogen mass flow rates for these initial two tests were only 1.5 to 1.8 lb_m/sec. Each of these preliminary LN_2 runs did however yield some valuable data. The compressor was operated at 8 000 to 8 500 rpm, resulting in a final heat exchanger bath pressure of 3.0 to 3.6 psia and production of subcooled LN_2 at 120 to 121 °R (see Table II). The flow rate and noise problems noted earlier were corrected prior to proceeding with the next LN_2 test. The mechanical start-up problem with the recirc pumps could not be resolved given the schedule constraints and inclement weather conditions, therefore the flow rate through the GSE was by pressurized transfer with the pump motors deenergized and the pumps free-spinning.

The compressor startup transient for the third LN_2 densification trial given in Fig. 13 shows the compressor ramping at 2 200 rpm/min to its set point speed of 8 000 rpm. Following a slight overshoot of controller speed, a compressor surge condition occurred 100 sec following the acceleration ramp as shown by the abrupt decline in speed to 7 500 rpm. The surge instability was quickly corrected by manually opening the gas bypass valve BV-2 to re-establish the compressor mass flow rate (Fig. 14) above 1.0 lb_m/sec gN_2. At 1500 sec into the LN_2 densification run, a steady-state condition was achieved. Compressor discharge and heat exchanger ullage pressures (Fig. 15) were leveling off at 15.3 and 3.7 psia, respectively. Compressor interstage temperatures (Fig. 16) were constant as indicated by a flat 150 °R adiabatic temperature rise across all four stages of the system. The LN_2 recirc mass flow rate (Fig. 17) was averaging 8.6 lb_m/sec through the GSE heat exchanger. The heat exchanger ther-mal performance(Fig. 18) shows that it produced 123 °R subcooled LN_2 at a nominal inlet temperature of 150 °R. The exchanger bath temperature reached a low point of 121 °R during the test, indicating a 2 °R exit end approach ΔT. The heat exchanger experimental ΔP across the tube bundle and manifolds ranged from 4.0 to 5.0 psid.

Liquid Hydrogen Densification Results

For the liquid hydrogen densification testing, the following target operating conditions were specified for the initial series of runs: 1.8 to 2.0 lb_m/sec LH_2 recirc mass flow rate, 1.4 to 1.8 psia heat exchanger bath pressure, and 22 000 rpm compressor operating speed. The compressor speed profile (Fig. 19) for the first LH_2 densification test (Run H1) shows the unit ramping at a linear rate of 2 200 rpm. Between 400 and 550 sec of the startup, the mass flow rate (Fig. 20) through the compressor was averaging 1.1 lb_m/sec of gH_2. At ~600 sec into GSE startup the compressor stopped accelerating as it approached 16 700 rpm. The compressor pressure-time data (Fig. 21) indicated a surge condition had developed 30 sec beforehand. Compressor interstage temperatures (Fig. 22) were running 30 to 40 °R below their design point predictions. Unlike the LN_2 densification test, manual operation of the gas-bypass valve BV-2 did not recover the compressor from the flow-reversal caused by the surge. The compressor shut itself down by a VFD over-current fault, interrupting operations at 630 sec. The heat exchanger bath pressure reached a low of 3.4 psia prior to the shut-down. With the LH_2 bath temperature at 29 °R, the heat exchanger outlet temperature attained 30°R (Fig. 23), indicating a 10 °R subcooling affect of the product stream near the end the startup transient. Liquid hydrogen mass flow rates (Fig. 24) varied from 2.0 to 2.3 lb_m/sec throughout the test. Two repeat attempts (Run H2 and H3) to startup the GSE compressor using this constant linear ramp procedure resulted in similar abort shutdowns after various run lengths.

A modified startup procedure was employed for the final LH_2 densification Run H4. The compressor was ramped incrementally in 2 000 rpm steps (Fig. 25) starting with operational verification at 10 000 rpm. The GSE was then allowed to reach pseudo-steady state conditions in order to stabilize the operation before the next step change increase in compressor speed was programmed. Partial success was realized using this startup approach as the overall densification run time increased to 1110 sec in duration. With the exception of a controlled surge incident at 500 sec, the 13 psi ΔP produced by the compressor (Fig. 26) resulted in a final low point heat exchanger bath pressure of 2.9 psia. Hydrogen mass flow rate through the heat exchanger was a constant 2.0 lb_m/sec of liquid entering at 39 °R. The LH_2 temperature profile through the heat exchanger (Fig. 27) resulted in the production of a 29.3 °R LH_2 product stream at a bath temperature of 28.9 °R and minimum 0.4 °R exit end exchanger ΔT. At 1310 sec into the extended densification test, the compressor operation abruptly terminated with a similar VFD fault shutdown. Subsequent compressor restart attempts failed, resulting in an immediate stoppage. Follow-on inspection of the compressor system showed that the third stage thrust bearing had failed and the drive motor had shorted to ground, prematurely ending the testing phase of the program before completion of the entire planned densification matrix.

Analysis of GSE Performance Data

The GSE mass and energy balance around the heat exchanger are calculated by Eqs. (1) and (2) from experimental mass flow rate, temperature and pressure data.

$$\dot{m}_{L_{in}} + \dot{m}_{V_{in}} - \dot{m}_{V_{out}} = \frac{d(\rho_L \bullet V_L)_{bath}}{dt} \tag{1}$$

$$\dot{m}_{L_{in}} h_{L_{in}} + \dot{m}_{V_{in}} h_{V_{in}} + \dot{m}_R \left(h_{R_{in}} - h_{R_{out}}\right) + Q_{env} - \dot{m}_{V_{out}} h_{V_{out}} = \frac{d(M_L \bullet V_L)_{bath}}{dt} \tag{2}$$

Based on the heat exchanger bath level fluctuating, results of integrated densification mass balance data is given in Fig. 28. Initial bath quantities for LH_2 and LN_2 were estimated to be 240 and 2750 lb_m, respectively. The mass sum totals for the five tests shown are 2600 lb_m of liquid in for heat exchanger level control plus bypass gas in, 3100 lb_m of vapor boil-off out to the compressor inlet, and 200 lb_m of bath density mass change ($V \bullet d\rho/dt$). The vapor boil-off mass out is 500 lb_m (i.e. 19 percent) greater than the liquid plus gas bypass mass in. The combined experimental mass balance on the bath indicates a 700 lb_m (i.e. 23 percent) total reduction of initial bath mass. This result confirmed experimental records denoting slow response to bath level change. The heat exchanger fill and level control valve (PCV-3) sometimes had difficulty keeping up with and maintaining a constant bath liquid level. This was attributed to the common dewar feed line plumbing and equivalent H-24 dewar pressure supplying liquid to the GSE. During portions of the densification tests, the heat exchanger bath level gradually dropped below the lower control point when the boil-off flow rate was high therefore requiring a greater bath level flow.

Integration of the energy Eq. (2) provides another use-ful insight into the test data. The energy balance test results for the GSE heat exchanger bath (Fig. 29) compare the energy added with the bypass gas flow, the heat transferred to the product liquid for subcooling, the energy rejected with the vent gas flow due to boil-off and other unaccounted for system energy changes. Energy totals for the five tests shown indicate 57 000 Btu in with bypass gas, 100 000 Btu of heat transferred for cryogen subcooling, 181 000 Btu of energy rejected with the vent gas and 24 000 Btu unaccounted. Based on the ratio of heat transferred to the fluid and the energy rejected with the vent gas, the thermal efficiency of the GSE start-up process was 55 percent. At design point steady-state operating conditions, the GSE thermal efficiency should increase to ~98 percent. The average and peak heat exchanger experimental subcooling duties calculated were 28 and 42 Btu/sec, respectively.

Heat exchanger inlet, outlet and axial wall temperature data (Fig. 30) is shown as a function of tube length for LH_2 run H1. Recall that a single heat exchanger tube was outfitted with five SiD's to provide wall temperature profile information as liquid flows through a tube. Experimental log-mean ΔT, heat transfer rate (Q) and overall heat transfer coefficient (U_o) values are indicated on the chart. Results of the transient wall temperature data show that the wall $\Delta T = T_w - T_{bath}$ varied from 1.8 °R at the inlet to 0.3 °R at the heat exchanger outlet. A comparison of the experimental data with the GSE heat exchanger performance model was also made. The analytical model showed good agreement of ±0.5 °R with the wall temperature data. Predicted heat exchanger outlet temperatures were acceptable to within 0.7 °R of the outlet LH_2 temperature data point.

A detailed performance analysis of the gN_2 and gH_2 compressor data was conducted for the following reasons: to ascertain whether the compressor performance satisfied design point and manufacturer performance specifications during GSE testing; to verify the cause and solution to the surge problems that frequently occurred during operation; and to possibly identify the source of the stage no. 3 drive failure. Review of the gN_2 test data (Fig. 31) showed that the compressor operated satisfactorily and within its design margin at the re-rated conditions established for pumping dry nitrogen gas. The nominal run point conditions matched the estimated gN_2 performance of 8000 rpm, 3.0 psia bath pressure and 1.0 lb/sec gN_2 flow. From Eqs. (3) to (5), the calculated gas horsepower (GHP) and head (Ψ) versus flow coefficient (ϕ) data estimated for the LN_2 test indicated that the experimental performance compared very favorably to the manufacturers original shop air test data. The compressor power requirements for each stage running steady at 8000 rpm showed that all the drive motors were ~90 percent power loaded during the LN_2 test.

$$GHP = \frac{H \bullet \dot{m}_V}{550 \bullet \eta} \tag{3}$$

$$\Psi = \frac{32.2 \bullet H}{U_2^2} \tag{4}$$

$$\phi = \frac{C_{in2}}{U_2} \tag{5}$$

For the LH_2 compressor test series, while assuming that only "dry" gH_2 entered the first compressor stage, the calculated head and flow coefficient data resulted in first and second stage Ψ and Φ coefficients that were extremely high in comparison to the previous gN_2 and manufacturers data (Fig. 32). The Ψ and Φ data points were 40 to 60 percent to the far right of the curve and well off the known compressor performance map. Furthermore, upon review of the hydrogen inlet temperature and corresponding saturation temperature data, obtained from known inlet pressures for stages 1 to 3, showed that the gas was saturated entering these stages (Fig 33). Additional calculations suggested that the hydrogen gas contained entrained LH_2 and was wet with a quality ranging from ~90 to 98 percent. The calculated power requirements for each stage during the hydrogen test H4 and prior to the failure indicated that the first stage motor was 88 percent loaded, the second stage 102 percent loaded, the third stage 111 percent loaded and the fourth stage was running at 107 percent of full load power. These experimental findings would imply that the third stage drive motor failure was probably induced by a sustained current overload of the stage no. 3 drive motor due to the wet saturated conditions and relatively higher density gH_2 vapor that was entering the compressor system during the run.

Conclusions

Propellant densification is a technology concept for increasing the performance of cryogenic LOX and LH_2 propulsion systems of the future. For an SSTO or RLV the use of supercooled, densified LOX/LH_2 propellants can significantly impact the vehicle design. Its been shown that densified propellants can benefit an RLV by reducing the gross lift-off weight by as much as 32 percent. For existing vehicles like the Space Shuttle, the use of densified fuels would result in a payload increase of 6 000 to 8,000 lb.

This paper described a test program conducted by the NASA LeRC to demonstrate the LH_2 propellant densification technology approach. The work was funded under NASA Contract NCC8-79 by the MSFC. A 2 lb/sec capacity, prototype-subscale, LH_2 densification Ground Support Unit, was designed, built and tested. Densification performance tests, based on a compressor-heat exchanger unit operating on a thermodynamic vent principle, were conducted using cryogenic LN_2 and LH_2. The initial series of experiments with the GSE occurred in December 1996 at the NASA Plum Brook, K-Site test facility, located in Sandusky OH. Three LN_2 and four LH_2 densification tests were run. The fundamental densification technology was first satisfactorily demonstrated with the safe inert working fluid LN_2. Liquid nitrogen was sub-cooled and densified from 148 to 123 °R at a flow rate of 9 lb/sec through the heat exchanger operating at 3.7 psia. During liquid hydrogen testing, compressor start-up problems caused by surge initially plagued the experiments. A modification to the start-up procedure eventually resulted in an extended LH_2 densification test run. Two pounds per second of NBP LH_2 was subcooled and densified by a 10 °R ΔT prior to an equipment failure of the compressor stage no. 3 drive motor. The following conclusions, technical issues and lessons learned can be drawn from these preliminary experimental densification results.

- The fundamental densification technology and design concept for subcooling cryogenic fluids based on this GSE approach has been confirmed. This same system philosophy can be extended to processing other cryogens including liquid oxygen.

- The performance of the multistage centrifugal compressor during hydrogen testing was affected by wet saturated gH_2 vapor entering the inlet to the first stage. This condition contributed to the premature failure due to an overload of that drive.

- The thermal performance of the cryogenic LH_2 heat exchanger was better than expected based on the close exit end operating ΔTs of the unit processing LH_2.

- Engineering solutions for each of the technical problems encountered with the GSE during this preliminary demonstration have been defined. For example, a piping change involving the relocation of the gH_2 bypass line from the heat exchanger LH_2 bath to the inlet of the first compressor stage is the hardware fix required to prevent the wet inlet gas condition. Corrective actions prior to further demonstration tests of the GSE densification rig are planned.

The interest in densified fuels for rocket engines has recently grown throughout the aerospace community. Because propellant densification potentially represents a major state-of-the-art advancement in cryogenic propulsion technology, it's recommended that this important work be continued. Ongoing research and testing will be necessary to bring this propellant technology to the next level leading to successful commercial development and application.

Acknowledgement

The author would like to extend his appreciation to Gordon MacKay and technical staff members of Sierra Lobo Inc. at the NASA LeRC Plum Brook Station for their enduring operations support. Special thanks are given to Doug Bewley of LeRC, Tibor Lak of Boeing North American and James Fesmire of NASA KSC for their technical contributions to the propellant densification design concept and test program. Recognition to Cryogenic Technical Services and Barber-Nichols is given for their contributions to the LH_2 GSE heat exchanger and compressor hardware designs, respectively.

Appendix A

Propellant Densification Test Data

The appendix contains three propellant densification test data sets. The results are given in a tabular format: data for LN_2 densification test number N3 is shown in Table A1; LH_2 densification test number H1 in Table A2; and LH_2 densification test number H4 in Table A3. Test data for LN_2 test numbers N1 and N2 were excluded due to problems with electrical noise on several data channels; LH_2 test numbers H2 and H3 are not reported because the data and trends are very similar to the test no. H1 data set provided in Table A2. Each table provides twenty-two different recorded measurements as a function of time on a five second scanned interval. The temperature, pressure and mass flow rate data obtained around the LH_2 heat exchanger and gH_2 compressor provides sufficient information for a complete performance assessment of the GSE unit densifier during startup, pseudo-steady state operation and shutdown.

Data Table Symbols :

Col.	Symbol	Description
1	——	time (sec)
2	PT1	heat exchanger inlet pressure (psia)
3	SD1	heat exchanger inlet temperature (°R)
4	FM2	heat exchanger inlet mass flow rate (lb/s)
5	PT6	heat exchanger outlet pressure (psia)
6	SD6B	heat exchanger outlet temperature (°R)
7	PT5B	heat exchanger ullage pressure (psia)
8	SD5A	heat exchanger ullage temperature (°R)
9	SD5B	heat exchanger bath temperature (°R)
10	FM3	heat exchanger bath level control flow (lb/s)
11	VFD3C	compressor speed (rpm)
12	PT10	compressor stg. 1 inlet pressure (psia)
13	SD10	compressor stg. 1 inlet temperature (°R)
14	PT11	compressor stg. 2 inlet pressure (psia)
15	SD11	compressor stg. 2 inlet temperature (°R)
16	PT12	compressor stg. 3 inlet pressure (psia)
17	SD12	compressor stg. 3 inlet temperature (°R)
18	PT13	compressor stg. 4 inlet pressure (psia)
19	SD13	compressor stg. 4 inlet temperature (°R)
20	PT14	compressor stg. 4 discharge pressure (psia)
21	SD14	compressor stg. 4 discharge temperature (°R)
22	FM4C	compressor discharge mass flow rate (lb/s)
23	FM5	gas bypass mass flow rate for surge control (lb/s)

TABLE A1.-LIQUID NITROGEN DENSIFICATION TEST NO. N3 DATA.

Time (sec)	PT1 (psia)	SD1 (R)	FM2 (lb/s)	PT6 (psia)	SD6B (R)	PT5B (psia)	SD5A (R)	SD5B (R)	FM3 (lb/s)	VFD3C (rpm)	PT10 (psia)	SD10 (R)	PT11 (psia)	SD11 (R)	PT12 (psia)	SD12 (R)	PT13 (psia)	SD13 (R)	PT14 (psia)	SD14 (R)	FM4C (lb/s)	FM5 (lb/s)
845	27.7	150.5	10.80	17.8	142.2	15.59	145.8	140.9	0.129	0	15.55	390.4	15.37	345.9	15.27	370.8	15.09	392.2	14.83	450.9	0.000	0.000
850	27.6	150.5	10.28	17.6	142.1	15.55	145.8	140.7	0.147	0	15.52	342.0	15.36	328.4	15.29	361.5	15.14	387.8	14.85	432.2	0.000	0.000
855	27.6	157.0	9.72	17.4	149.2	15.53	152.2	146.3	0.104	90	15.51	301.9	15.35	314.8	15.27	353.7	15.12	386.5	14.89	420.2	0.000	0.000
860	27.6	160.2	7.59	17.5	152.0	15.48	154.8	148.3	0.105	384	15.46	270.5	15.33	304.6	15.28	347.6	15.16	384.3	14.93	412.8	0.000	0.000
865	27.6	160.0	8.97	17.5	151.9	15.42	154.8	148.2	0.127	483	15.40	246.5	15.28	296.0	15.25	342.2	15.14	381.4	14.92	407.5	0.000	0.000
870	27.6	159.2	10.79	17.5	151.0	15.36	153.9	147.7	0.105	584	15.34	228.6	15.24	289.5	15.23	338.2	15.14	378.0	14.94	403.7	0.000	0.000
875	27.5	158.8	10.19	17.5	150.6	15.30	153.6	147.4	0.119	781	15.27	216.1	15.20	285.0	15.21	334.5	15.14	375.5	14.96	400.7	0.000	0.000
880	27.4	158.5	7.15	17.3	150.3	15.24	153.2	147.1	0.104	982	15.21	206.9	15.18	281.9	15.22	331.8	15.15	373.1	14.98	398.3	0.000	0.000
885	27.4	158.5	7.74	17.3	150.3	15.16	153.2	147.3	0.108	1183	15.13	200.1	15.15	279.4	15.21	329.3	15.17	371.0	15.01	396.0	0.000	0.000
890	27.3	158.6	10.18	17.3	150.5	15.07	153.5	147.4	0.109	1387	15.04	195.1	15.10	277.1	15.20	327.0	15.18	368.7	15.04	394.2	0.000	0.000
895	27.4	158.6	8.86	17.2	150.5	14.99	153.3	147.4	0.105	1589	14.96	191.0	15.08	275.1	15.21	324.9	15.21	366.8	15.07	392.3	0.000	0.000
900	27.4	158.3	6.25	17.0	150.3	14.86	153.0	147.1	0.110	1791	14.83	188.0	15.00	272.5	15.15	322.3	15.16	364.5	15.00	390.1	0.000	0.000
905	27.2	158.2	10.14	17.1	150.2	14.74	152.9	147.3	0.107	1990	14.70	185.3	14.94	269.6	15.14	319.4	15.18	362.0	15.04	388.2	0.000	0.000
910	27.3	158.5	8.53	17.1	150.5	14.62	153.3	147.3	0.103	2187	14.58	183.2	14.90	266.7	15.15	316.4	15.23	359.2	15.10	385.9	0.000	0.000
915	27.1	158.0	6.46	16.9	149.9	14.50	152.8	147.0	0.083	2389	14.46	181.0	14.86	263.5	15.17	313.3	15.27	356.7	15.16	383.8	0.483	0.000
920	27.2	157.9	9.64	16.9	149.7	14.37	152.5	146.9	0.118	2593	14.32	179.6	14.80	260.3	15.17	310.3	15.31	354.1	15.21	381.7	0.775	0.000
925	27.1	157.9	6.91	17.0	149.4	14.23	152.3	146.6	0.111	2795	14.19	178.5	14.76	257.0	15.19	307.4	15.37	351.4	15.27	379.4	0.826	0.000
930	27.2	158.0	8.93	16.9	149.6	14.08	152.6	146.9	0.111	2999	14.03	177.3	14.71	253.8	15.21	304.5	15.42	348.8	15.33	377.3	0.881	0.000
935	27.0	158.2	9.88	16.8	149.6	13.91	152.6	146.7	0.115	3197	13.85	176.2	14.63	250.8	15.20	301.5	15.46	346.3	15.39	375.1	0.933	0.000
940	26.9	158.3	9.02	16.7	149.7	13.76	152.8	146.9	0.112	3397	13.69	174.8	14.58	247.4	15.24	298.4	15.53	343.6	15.46	372.8	1.002	0.000
945	27.1	158.8	9.66	16.6	149.7	13.56	152.9	146.9	0.113	3601	13.49	173.8	14.52	244.5	15.26	295.5	15.61	340.7	15.54	370.5	1.064	0.000
950	26.9	159.0	9.53	16.6	149.9	13.34	153.2	147.1	0.111	3799	13.26	172.7	14.42	241.5	15.26	292.5	15.67	338.0	15.63	368.2	1.125	0.000
955	27.0	159.6	7.95	16.4	150.2	13.10	153.5	147.0	0.127	4001	13.03	171.9	14.32	238.6	15.28	289.5	15.74	335.3	15.72	365.8	1.192	0.000
965	27.0	160.7	10.50	16.1	151.0	12.62	154.5	147.6	0.094	4502	12.52	169.8	14.12	233.2	15.31	283.7	15.92	330.4	15.95	361.3	1.324	0.000
970	26.9	161.5	6.15	16.1	151.6	12.37	155.0	148.0	0.110	4705	12.26	168.8	14.02	230.3	15.34	280.5	16.03	327.7	16.07	359.0	1.405	0.000
975	26.8	162.4	8.58	15.8	152.2	12.10	155.6	148.2	0.095	4906	11.99	167.8	13.91	227.7	15.36	277.7	16.13	325.3	16.22	356.7	1.484	0.000
980	26.9	163.1	6.95	15.6	153.0	11.82	156.3	148.6	0.143	5207	11.69	166.5	13.79	225.1	15.38	274.8	16.24	322.9	16.37	354.3	1.571	0.000
985	26.5	164.1	10.01	15.5	153.6	11.52	157.2	149.0	0.097	5407	11.38	165.4	13.64	222.4	15.39	272.0	16.35	320.5	16.52	352.1	1.654	0.000
990	26.7	164.6	9.56	15.4	153.9	11.21	157.3	148.9	0.107	5707	11.06	164.0	13.48	220.2	15.38	269.5	16.45	318.2	16.66	349.8	1.727	0.000
995	26.6	165.3	4.80	15.2	154.3	10.88	157.6	149.3	0.131	5904	10.71	163.0	13.30	218.2	15.36	266.9	16.53	316.1	16.82	347.7	1.814	0.000
1000	26.5	165.7	6.30	15.3	154.5	10.54	157.9	149.3	0.099	6110	10.35	161.7	13.09	215.8	15.30	264.5	16.60	313.9	16.95	345.7	1.885	0.000
1005	26.6	166.8	6.56	15.2	155.5	10.18	158.8	148.4	0.096	6406	9.98	160.6	12.87	214.0	15.22	262.3	16.65	311.7	17.15	343.7	1.966	0.000
1010	26.5	167.2	5.55	15.1	155.5	9.83	158.8	148.0	0.168	6708	9.60	159.6	12.63	212.4	15.15	260.3	16.70	309.7	17.26	342.0	2.038	0.000
1015	26.3	167.9	6.33	15.0	155.9	9.48	159.7	148.0	0.091	6914	9.22	158.2	12.38	210.6	15.05	258.4	16.72	308.1	17.38	340.5	2.107	0.000

TABLE A1.-Continued

Time	PT1	SD1	FM2	PT6	SD6B	PT5B	SD5A	SD5B	FM3	VFD3C	PT10	SD10	PT11	SD11	PT12	SD12	PT13	SD13	PT14	SD14	FM4C	FM5
(sec)	(psia)	(R)	(lb/s)	(psia)	(R)	(psia)	(R)	(R)	(lb/s)	(rpm)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(lb/s)	(lb/s)
1020	26.5	168.4	6.15	15.1	156.0	9.11	160.0	147.9	0.096	7214	8.82	157.6	12.08	209.4	14.92	257.0	16.72	306.9	17.58	339.0	2.167	0.000
1025	26.5	168.8	6.34	15.1	156.0	8.74	160.0	147.9	0.132	7418	8.44	156.5	11.77	208.1	14.75	255.6	16.66	305.6	17.67	337.9	2.223	0.000
1030	26.4	168.6	6.34	15.1	155.6	8.37	160.3	147.3	0.106	7719	8.05	155.2	11.44	206.9	14.55	254.4	16.60	304.5	17.76	336.9	2.265	0.000
1035	26.5	169.2	6.93	15.1	155.5	8.03	160.6	147.4	0.131	7917	7.68	154.0	11.11	205.7	14.33	253.4	16.49	303.9	17.85	336.3	2.306	0.000
1040	26.4	169.3	6.50	15.0	155.2	7.68	160.3	146.7	0.145	8119	7.31	153.2	10.75	204.6	14.06	252.6	16.32	302.9	17.90	335.7	2.322	0.000
1045	26.3	169.5	6.59	15.2	154.8	7.33	160.0	146.0	0.104	8321	6.95	152.2	10.38	203.7	13.75	251.8	16.10	302.2	17.83	335.3	2.318	0.000
1050	26.5	169.6	6.95	15.1	154.5	7.02	160.6	145.7	0.109	8522	6.61	151.5	10.04	203.0	13.45	251.4	15.91	302.0	17.84	335.2	2.319	0.000
1055	26.4	169.8	6.90	15.0	154.0	6.72	159.6	145.3	0.135	8520	6.34	150.3	9.66	202.3	13.03	250.9	15.52	301.4	17.59	335.1	2.247	0.000
1060	26.6	169.3	7.16	15.1	153.0	6.43	159.7	144.5	0.137	8423	6.07	149.3	9.27	201.1	12.57	249.8	15.13	300.1	17.33	334.2	2.144	0.000
1065	26.6	169.2	7.06	15.3	152.3	6.19	159.2	143.7	0.135	8422	5.84	148.7	8.95	199.9	12.17	248.4	14.77	298.7	17.05	333.0	2.038	0.000
1070	26.3	168.9	7.29	15.2	151.5	5.97	158.9	142.9	0.109	8320	5.64	147.9	8.67	198.8	11.83	247.1	14.44	297.4	16.82	331.9	1.945	0.000
1075	26.4	168.8	7.37	15.0	150.7	5.78	158.3	142.5	0.113	8320	5.47	147.1	8.42	197.9	11.54	245.8	14.17	295.9	16.64	330.8	1.867	0.000
1080	26.6	168.5	6.84	15.1	150.0	5.58	158.3	141.9	0.166	8222	5.29	146.6	8.19	196.8	11.24	244.6	13.93	294.5	16.48	329.8	1.786	0.000
1085	26.3	168.2	7.08	15.1	149.3	5.39	157.0	141.3	0.100	8222	5.11	146.1	7.95	195.9	10.95	243.6	13.69	293.2	16.32	328.8	1.712	0.000
1090	26.5	168.2	6.84	15.3	148.9	5.25	156.9	140.7	0.123	8224	4.98	145.3	7.77	195.1	10.72	242.5	13.50	291.8	16.20	327.7	1.645	0.000
1095	26.4	167.9	7.05	15.2	148.2	5.11	156.9	140.4	0.102	8123	4.86	145.1	7.60	194.2	10.52	241.5	13.34	290.8	16.10	326.8	1.579	0.000
1100	26.3	167.7	6.89	15.2	147.7	4.99	156.8	140.2	0.103	8123	4.74	144.7	7.45	193.6	10.37	240.5	13.20	289.8	16.00	326.0	1.512	0.000
1105	26.5	167.4	6.87	15.1	147.1	4.87	155.6	139.7	0.132	8117	4.63	144.2	7.30	192.6	10.22	239.7	13.05	289.1	15.91	325.5	1.454	0.000
1110	26.3	167.1	6.71	15.1	146.7	4.77	155.5	139.7	0.128	8020	4.54	143.8	7.18	192.1	10.07	239.2	12.92	288.4	15.82	325.2	1.391	0.000
1115	26.3	166.8	6.70	15.1	146.0	4.67	154.8	138.7	0.088	8019	4.46	143.4	7.07	191.4	9.95	238.5	12.79	287.9	15.73	325.1	1.331	0.000
1120	26.1	153.8	10.39	15.4	130.2	4.65	142.5	126.8	0.372	8020	4.44	142.9	7.04	190.9	9.91	238.3	12.75	287.1	15.69	325.2	1.283	0.000
1125	25.7	153.6	9.14	15.5	129.8	4.62	138.7	126.6	0.943	8020	4.41	142.6	7.01	190.6	9.88	237.7	12.73	286.8	15.67	325.1	1.273	0.000
1130	25.4	153.5	10.49	15.3	129.6	4.55	141.2	126.6	0.667	8019	4.35	142.5	6.93	190.3	9.80	237.6	12.65	286.7	15.60	325.0	1.252	0.000
1135	25.3	153.2	10.28	15.3	129.3	4.51	141.8	126.5	0.660	8021	4.32	142.3	6.90	190.0	9.75	237.2	12.60	286.7	15.55	325.2	1.222	0.000
1140	25.1	153.2	10.61	15.6	129.2	4.46	129.0	126.3	0.723	8020	4.28	142.2	6.84	189.9	9.68	237.3	12.53	286.8	15.47	325.6	1.179	0.000
1145	25.0	153.0	10.35	15.2	129.2	4.42	129.9	126.5	0.615	7918	4.26	141.9	6.82	189.9	9.64	237.5	12.48	287.2	15.40	326.2	1.121	0.000
1150	24.9	152.8	10.61	15.5	128.9	4.40	137.9	126.2	0.555	7921	4.25	141.8	6.79	189.9	9.59	238.0	12.42	287.9	15.33	327.2	1.068	0.000
1155	24.9	152.5	9.56	15.2	128.6	4.39	139.0	126.2	0.529	7922	4.26	141.6	6.77	190.2	9.53	238.8	12.31	288.9	15.20	328.3	0.989	0.000
1160	24.7	150.5	10.13	15.2	126.8	5.32	138.4	125.0	0.634	7631	5.31	141.6	6.93	191.8	8.97	240.6	11.27	289.2	13.80	329.8	0.695	0.000
1165	24.6	150.6	8.38	15.2	126.8	5.93	143.2	125.0	0.544	7522	5.92	167.5	7.39	201.7	9.21	248.1	11.38	295.4	13.72	335.6	0.212	0.000
1170	24.7	150.5	7.91	15.2	126.8	6.03	152.5	125.0	0.792	7522	6.00	186.6	7.24	210.5	8.99	255.0	11.10	300.6	13.57	340.9	0.102	0.000
1175	24.6	150.5	9.23	15.4	126.9	6.37	152.5	125.0	0.886	7522	6.27	198.4	7.64	216.2	9.69	259.3	11.70	303.4	13.87	344.2	0.073	0.000
1180	24.6	150.5	10.13	15.3	127.1	6.74	157.9	125.1	0.589	7522	6.70	205.6	7.87	219.9	9.56	262.2	11.19	306.0	13.05	346.9	0.024	0.000
1185	24.5	150.5	11.37	15.1	127.2	6.92	160.6	125.4	0.713	7521	6.88	210.5	8.00	222.7	9.70	265.0	11.35	308.5	13.13	349.2	0.017	0.000

TABLE A1.-Continued

Time	PT1	SD1	FM2	PT6	SD6B	PT5B	SD5A	SD5B	FM3	VFD3C	PT10	SD10	PT11	SD11	PT12	SD12	PT13	SD13	PT14	SD14	FM4C	FM5
(sec)	(psia)	(R)	(lb/s)	(psia)	(R)	(psia)	(R)	(R)	(lb/s)	(rpm)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(lb/s)	(lb/s)
1190	24.3	150.5	9.42	15.1	127.5	7.13	161.7	125.6	0.616	7522	7.08	214.1	8.08	224.8	9.60	266.9	11.12	310.3	12.88	350.9	0.022	0.000
1195	24.3	150.5	8.41	15.1	127.8	7.19	162.2	125.7	0.683	7522	7.07	216.9	8.09	226.4	9.76	268.6	11.47	311.8	13.32	352.3	0.024	0.000
1200	24.4	150.6	8.06	15.1	128.1	7.13	162.4	126.2	0.839	7522	7.20	219.5	8.09	227.9	9.58	270.0	11.27	313.1	13.06	353.5	0.024	0.000
1205	24.0	150.2	8.75	15.0	128.6	7.48	163.4	126.3	0.904	7524	7.44	221.4	8.17	229.5	9.52	271.1	11.02	313.9	12.65	354.3	0.036	0.000
1210	23.9	150.0	10.24	15.0	128.4	7.78	164.6	126.3	0.463	7524	7.75	222.8	8.53	230.6	9.97	271.9	11.57	314.4	13.34	355.1	0.048	0.000
1215	23.8	150.0	7.93	15.0	128.9	7.81	164.7	126.6	0.723	7524	7.73	224.7	8.60	231.7	10.04	272.8	11.52	315.1	13.05	355.4	0.052	0.000
1220	23.9	149.9	8.83	15.0	129.0	7.95	165.6	126.8	0.873	7522	7.92	226.1	8.52	232.9	9.62	273.4	10.84	315.4	12.14	356.0	0.054	0.020
1225	23.8	149.6	9.88	15.0	129.2	8.34	164.8	126.9	0.969	7522	8.29	227.3	8.90	233.8	9.96	274.0	11.07	315.6	12.16	356.2	0.070	0.053
1230	23.8	151.3	8.83	15.2	130.7	7.04	168.2	128.0	0.652	7518	6.85	229.3	9.35	235.1	11.72	274.6	13.55	317.2	14.47	356.2	0.128	0.119
1235	23.7	152.2	7.52	14.8	132.0	5.93	154.6	128.7	0.884	8221	5.61	183.3	8.63	218.5	11.68	263.4	14.15	307.5	16.36	342.7	1.214	0.195
1240	23.8	152.3	8.57	15.1	132.2	5.73	149.3	128.7	0.969	8422	5.37	149.9	8.71	202.7	12.11	252.3	14.67	298.7	16.82	333.9	1.788	0.236
1245	23.6	152.5	9.98	14.9	132.0	5.61	149.2	129.2	0.638	8422	5.19	137.5	8.62	191.0	12.17	243.6	14.82	292.0	17.00	328.1	2.054	0.241
1250	23.7	152.5	8.61	15.2	132.0	5.47	149.2	129.2	0.622	8520	5.04	133.5	8.39	172.4	11.95	233.2	14.67	284.2	16.98	321.9	2.222	0.243
1255	23.6	152.5	9.22	15.0	131.9	5.36	148.3	129.2	0.888	8420	4.92	132.3	8.14	172.4	11.60	229.1	14.32	280.5	16.70	318.9	2.091	0.243
1260	23.6	152.5	9.93	15.4	131.7	5.25	148.6	128.7	0.950	8420	4.81	131.7	8.07	170.7	11.61	225.5	14.36	277.5	16.75	316.1	2.085	0.244
1265	23.6	152.5	6.80	15.0	131.6	5.15	149.2	128.4	0.618	8522	4.72	131.4	7.87	166.7	11.54	221.4	14.33	273.8	16.79	312.8	2.129	0.246
1270	23.7	152.6	8.60	15.1	131.6	5.04	148.7	128.4	0.622	8522	4.57	131.3	7.73	161.3	11.36	216.7	14.21	269.9	16.78	309.5	2.153	0.247
1275	23.6	152.6	10.20	15.1	131.3	4.94	148.0	128.3	0.926	8422	4.52	130.8	7.53	160.5	10.98	214.1	13.83	267.1	16.50	307.1	2.074	0.246
1280	23.7	152.8	6.59	15.2	131.0	4.86	147.9	128.3	0.975	8323	4.41	130.5	7.42	161.9	10.90	213.2	13.76	265.5	16.43	305.5	1.982	0.246
1285	23.5	152.6	8.36	15.0	131.0	4.78	147.3	127.8	0.553	8423	4.37	130.5	7.33	159.3	10.80	210.6	13.72	263.0	16.48	303.1	2.039	0.247
1290	23.6	152.6	10.37	15.1	130.8	4.70	147.3	127.7	0.798	8420	4.27	130.2	7.19	159.0	10.68	209.3	13.63	261.2	16.41	301.2	1.970	0.247
1295	23.6	152.5	6.93	15.3	130.5	4.61	147.4	127.4	0.964	8423	4.23	130.1	7.10	155.9	10.55	206.6	13.51	258.4	16.39	299.0	2.010	0.248
1300	23.4	152.5	8.08	15.0	130.2	4.54	146.4	127.2	0.925	8422	4.14	129.8	7.00	154.2	10.45	204.6	13.47	256.3	16.39	296.9	1.982	0.249
1305	23.5	152.6	10.10	14.9	129.9	4.48	146.7	127.2	0.563	8323	4.10	129.6	6.91	154.5	10.38	203.6	13.44	254.8	16.35	295.1	1.932	0.249
1310	23.5	152.3	7.43	15.1	129.6	4.41	146.0	126.9	0.773	8323	4.00	129.2	6.70	153.5	10.02	201.9	13.09	252.6	16.14	293.1	1.908	0.248
1315	23.4	152.3	9.12	15.0	129.5	4.38	145.0	126.8	1.077	8321	4.03	129.0	6.55	152.9	10.04	201.0	13.18	251.6	16.20	291.7	1.892	0.249
1320	23.4	152.5	8.62	15.1	129.3	4.31	144.5	126.5	0.871	8321	3.93	129.0	6.61	148.4	10.10	198.4	13.23	249.0	16.29	289.3	1.902	0.251
1325	23.4	152.3	8.98	14.9	129.2	4.28	143.9	126.3	1.091	8323	3.93	128.9	6.31	148.7	9.71	197.4	12.94	247.4	16.12	287.9	1.858	0.250
1330	23.4	152.2	9.47	15.3	129.0	4.21	143.5	126.0	1.068	8320	3.74	128.3	6.36	147.3	9.64	195.6	12.83	245.6	16.06	286.1	1.862	0.250
1335	23.4	152.3	7.82	15.4	128.9	4.18	143.9	126.0	1.019	8318	3.86	128.6	6.12	137.4	9.56	193.8	12.82	243.8	16.11	284.4	1.853	0.251
1340	23.3	152.2	9.34	15.1	128.7	4.13	142.9	125.7	0.876	8320	3.75	128.3	6.27	141.3	9.51	192.1	12.70	242.0	16.00	282.5	1.836	0.251
1345	23.3	152.2	8.11	15.0	128.4	4.10	142.2	125.6	0.974	8218	3.75	128.1	6.28	147.0	9.56	193.0	12.76	242.4	16.01	282.4	1.747	0.251
1350	23.2	152.2	10.31	15.2	128.4	4.05	141.9	125.3	1.028	8219	3.69	127.8	6.21	149.7	9.44	193.6	12.63	242.0	15.91	281.8	1.713	0.251
1355	23.3	152.0	7.72	15.2	128.1	4.01	141.9	125.3	1.064	8219	3.63	127.7	6.13	150.6	9.33	193.4	12.54	241.5	15.86	281.0	1.707	0.251

TABLE A1.-Continued

Time	PT1	SD1	FM2	PT6	SD6B	PT5B	SD5A	SD5B	FM3	VFD3C	PT10	SD10	PT11	SD11	PT12	SD12	PT13	SD13	PT14	SD14	FM4C	FM5
(sec)	(psia)	(R)	(lb/s)	(psia)	(R)	(psia)	(R)	(R)	(lb/s)	(rpm)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(lb/s)	(lb/s)
1360	23.4	152.0	10.17	15.3	128.1	3.96	141.0	125.1	0.569	8219	3.62	127.5	6.13	151.9	9.32	193.6	12.52	241.4	15.85	280.6	1.651	0.251
1365	23.8	152.2	7.99	15.0	128.0	3.93	140.2	125.1	0.303	8218	3.56	127.2	6.05	151.6	9.18	193.3	12.38	240.6	15.77	279.9	1.633	0.250
1370	23.9	152.2	9.55	15.2	127.7	3.89	139.3	124.8	0.403	8219	3.55	127.2	5.98	149.2	9.13	191.9	12.34	239.3	15.76	278.5	1.670	0.251
1375	23.9	152.3	9.44	15.4	127.5	3.90	139.6	124.8	0.844	8221	3.56	127.2	6.04	151.0	9.18	192.2	12.38	239.4	15.77	278.5	1.581	0.251
1380	23.6	152.5	7.54	15.1	127.7	3.88	139.9	124.8	0.889	8219	3.50	127.7	5.97	150.6	9.13	191.8	12.35	239.0	15.77	277.8	1.625	0.252
1385	23.4	152.6	8.46	14.9	127.7	3.86	139.3	124.7	0.935	8219	3.51	127.5	5.96	150.6	9.12	191.7	12.35	238.5	15.77	277.1	1.605	0.252
1390	23.3	152.5	9.32	15.0	127.5	3.81	139.4	124.5	1.025	8218	3.49	127.5	5.88	149.6	8.97	190.7	12.20	237.5	15.67	276.2	1.612	0.251
1395	23.3	152.3	9.27	15.8	127.5	3.77	139.1	124.5	1.011	8117	3.47	127.1	5.84	152.5	8.87	191.7	12.05	238.1	15.50	276.7	1.486	0.250
1400	23.1	152.9	6.59	15.4	128.4	3.77	139.6	125.0	1.062	8119	3.47	126.8	5.87	154.8	8.89	192.8	12.07	238.6	15.50	277.5	1.438	0.250
1405	23.1	153.5	10.11	14.9	128.9	3.76	139.9	125.3	1.024	8117	3.45	126.8	5.85	155.3	8.86	193.3	12.05	239.2	15.51	277.6	1.444	0.250
1410	23.2	153.6	6.49	15.1	128.7	3.74	139.7	125.3	1.011	8117	3.41	126.9	5.85	154.5	8.98	193.4	12.20	239.0	15.64	277.3	1.473	0.251
1415	23.1	153.5	9.66	15.0	128.7	3.71	139.6	125.3	0.980	8119	3.42	126.6	5.80	153.2	8.85	192.5	12.04	238.1	15.53	276.2	1.482	0.250
1420	23.2	153.5	6.79	14.9	128.7	3.70	139.3	125.1	0.906	8119	3.43	126.6	5.85	154.0	8.93	192.8	12.13	238.3	15.60	276.3	1.443	0.251
1425	23.2	153.6	9.24	14.9	128.7	3.69	138.2	125.1	1.017	8119	3.41	126.5	5.80	154.0	8.83	192.8	12.02	238.1	15.51	276.2	1.439	0.250
1430	23.2	153.6	8.08	15.3	128.7	3.68	138.7	125.1	0.985	8120	3.39	126.6	5.79	154.2	8.87	192.8	12.08	238.0	15.53	275.9	1.436	0.251
1435	23.3	153.6	8.34	14.9	128.6	3.67	138.7	125.1	1.044	8119	3.38	126.6	5.77	154.5	8.77	192.8	11.96	238.1	15.45	275.9	1.408	0.250
1440	23.2	153.5	9.45	15.3	128.4	3.66	138.5	124.8	0.923	8120	3.38	126.6	5.77	154.8	8.77	192.9	11.97	238.0	15.46	275.8	1.407	0.250
1445	23.1	153.6	8.20	15.1	128.6	3.64	138.1	125.0	1.031	8119	3.37	126.6	5.76	154.9	8.76	193.2	11.96	238.1	15.45	275.7	1.402	0.250
1450	23.1	153.6	10.03	15.1	128.3	3.65	137.9	124.8	1.105	8120	3.36	126.6	5.75	155.2	8.74	193.2	11.93	238.3	15.42	275.6	1.389	0.250
1455	23.1	153.6	7.22	14.9	128.4	3.63	137.9	124.8	1.064	8117	3.36	126.6	5.73	155.0	8.72	193.2	11.92	238.0	15.42	275.4	1.393	0.250
1460	23.0	153.8	9.55	14.7	128.6	3.63	137.8	125.0	1.125	8119	3.35	126.5	5.79	154.8	8.81	193.2	12.03	238.0	15.55	275.3	1.397	0.252
1465	23.1	153.6	7.02	15.0	128.4	3.61	137.5	124.8	1.182	8119	3.33	126.5	5.70	152.8	8.70	192.1	11.91	236.8	15.45	274.2	1.441	0.251
1470	23.2	153.5	9.77	14.9	128.3	3.61	137.4	124.5	1.206	8117	3.34	126.3	5.71	154.3	8.67	192.3	11.87	237.2	15.34	274.4	1.358	0.250
1475	23.1	153.5	7.22	15.0	128.1	3.60	136.5	124.7	1.190	8019	3.35	126.5	5.69	156.0	8.65	193.3	11.83	238.1	15.32	275.3	1.310	0.250
1480	23.2	153.3	8.48	15.2	128.0	3.59	136.8	124.7	1.164	8019	3.35	126.3	5.70	157.3	8.67	194.2	11.83	239.0	15.29	276.1	1.270	0.249
1485	23.1	153.5	8.82	15.0	128.1	3.60	136.8	124.5	1.202	8017	3.37	126.5	5.73	158.0	8.68	194.9	11.85	239.8	15.32	276.5	1.283	0.249
1490	23.1	153.5	8.39	14.9	128.1	3.61	136.8	124.5	1.186	8019	3.38	126.5	5.77	158.0	8.73	195.5	11.91	239.9	15.40	276.5	1.305	0.250
1495	23.1	153.6	9.59	15.1	128.3	3.59	136.6	124.7	1.062	8120	3.35	126.8	5.76	156.2	8.78	194.9	12.01	239.3	15.52	275.7	1.375	0.252
1500	23.1	153.6	8.61	14.8	128.1	3.59	136.5	124.5	1.149	8119	3.31	126.2	5.69	154.8	8.67	193.7	11.87	237.9	15.39	274.4	1.378	0.251
1505	23.1	153.6	6.87	15.1	128.1	3.59	136.5	124.5	1.186	8119	3.31	126.5	5.70	154.8	8.66	193.4	11.87	237.7	15.39	274.2	1.359	0.251
1510	23.0	153.5	8.51	14.9	128.1	3.58	136.3	124.5	1.191	8117	3.32	126.5	5.71	154.3	8.70	192.9	11.92	237.5	15.44	273.9	1.375	0.252
1515	23.1	153.5	8.86	15.1	128.1	3.55	135.9	124.5	1.155	8119	3.30	126.2	5.66	154.0	8.62	192.5	11.82	236.8	15.33	273.4	1.363	0.251
1520	23.0	153.3	8.99	15.0	127.8	3.56	135.4	124.4	1.202	8019	3.31	126.2	5.67	155.5	8.62	193.0	11.80	237.3	15.30	273.9	1.300	0.250
1525	23.1	153.3	7.98	15.1	128.0	3.55	135.7	124.5	1.118	8019	3.30	126.3	5.65	156.3	8.63	193.8	11.81	238.3	15.28	274.4	1.283	0.250

TABLE A1.-Continued

Time (sec)	PT1 (psia)	SD1 (R)	FM2 (lb/s)	PT6 (psia)	SD6B (R)	PT5B (psia)	SD5A (R)	SD5B (R)	FM3 (lb/s)	VFD3C (rpm)	PT10 (psia)	SD10 (R)	PT11 (psia)	SD11 (R)	PT12 (psia)	SD12 (R)	PT13 (psia)	SD13 (R)	PT14 (psia)	SD14 (R)	FM4C (lb/s)	FM5 (lb/s)
1530	23.0	153.3	8.79	15.1	127.8	3.55	134.8	124.4	1.183	8019	3.31	126.2	5.67	156.6	8.63	194.2	11.81	238.4	15.30	274.6	1.289	0.250
1535	23.0	153.3	5.98	15.2	127.8	3.55	135.3	124.4	1.157	8017	3.31	126.2	5.68	156.9	8.65	194.7	11.83	238.6	15.31	274.9	1.284	0.250
1540	23.1	153.2	8.66	15.1	127.7	3.56	135.1	124.4	1.165	8016	3.30	126.0	5.68	156.8	8.64	194.7	11.81	238.6	15.31	274.6	1.288	0.250
1545	23.2	153.3	10.26	15.5	128.0	3.56	135.1	124.2	1.159	8116	3.30	126.3	5.70	156.3	8.69	194.5	11.89	238.5	15.41	274.4	1.329	0.252
1550	23.4	153.3	7.27	15.2	127.8	3.54	134.8	124.4	1.184	8116	3.30	126.2	5.66	155.2	8.62	193.7	11.83	237.6	15.36	273.5	1.354	0.251
1555	23.5	152.6	10.08	15.1	126.8	3.55	131.7	123.8	1.176	8016	3.29	125.9	5.64	156.3	8.60	193.8	11.77	237.7	15.26	273.7	1.279	0.250
1560	23.6	152.8	7.48	15.4	127.1	3.57	133.8	123.8	1.186	8017	3.32	126.2	5.67	157.0	8.63	194.7	11.81	238.5	15.31	274.3	1.267	0.251
1565	23.8	152.8	10.33	15.3	126.9	3.57	134.1	123.6	1.157	8017	3.30	126.0	5.64	157.5	8.60	194.9	11.78	238.6	15.26	274.4	1.261	0.250
1570	24.3	152.9	8.58	15.4	126.9	3.58	134.0	123.8	1.201	8019	3.34	126.0	5.70	157.9	8.64	195.2	11.81	238.9	15.30	274.4	1.265	0.251
1575	24.4	153.0	8.80	15.7	126.9	3.59	133.7	123.8	1.140	8017	3.35	126.2	5.70	158.3	8.63	195.6	11.79	239.0	15.29	274.4	1.263	0.251
1580	24.4	153.3	10.40	15.0	127.1	3.60	133.8	123.9	1.168	8017	3.36	126.2	5.71	158.9	8.65	196.0	11.81	239.2	15.32	274.6	1.264	0.251
1585	24.6	153.3	8.45	15.0	127.1	3.61	134.0	123.8	1.137	8017	3.36	126.2	5.71	159.2	8.64	196.1	11.79	239.2	15.29	274.4	1.261	0.251
1590	24.7	153.6	9.92	15.0	127.1	3.63	134.0	123.9	1.086	8017	3.38	126.2	5.74	159.7	8.66	196.3	11.83	239.4	15.31	274.4	1.262	0.251
1595	24.6	153.6	11.38	15.1	127.1	3.63	133.7	123.9	1.096	8017	3.38	126.3	5.73	159.7	8.65	196.4	11.82	239.4	15.32	274.3	1.262	0.251
1600	24.7	153.6	9.79	15.0	127.1	3.63	133.8	123.9	1.188	8019	3.39	126.5	5.72	160.2	8.64	196.7	11.79	239.3	15.27	274.3	1.257	0.251
1605	24.6	153.8	8.42	15.3	127.1	3.63	133.7	123.9	1.092	8017	3.39	126.3	5.73	161.0	8.64	197.1	11.79	239.8	15.27	274.6	1.255	0.251
1610	24.6	153.6	8.82	15.6	127.2	3.65	133.7	123.9	1.072	8019	3.40	126.3	5.76	161.2	8.66	197.5	11.81	239.9	15.31	274.8	1.256	0.251
1615	24.8	153.8	9.98	15.8	127.2	3.64	133.7	123.9	1.217	8019	3.38	126.5	5.73	161.3	8.65	197.6	11.81	239.9	15.28	274.6	1.255	0.251
1620	24.8	153.8	10.10	15.2	127.2	3.66	133.7	124.1	1.108	8017	3.41	126.5	5.77	161.3	8.68	197.6	11.83	240.1	15.33	274.6	1.257	0.251
1625	24.7	153.9	10.98	15.0	127.4	3.66	133.5	124.2	1.201	8019	3.41	126.5	5.78	160.7	8.69	197.4	11.85	239.8	15.35	274.3	1.260	0.252
1630	24.6	153.9	10.58	15.3	127.4	3.67	133.7	124.1	1.074	8020	3.41	126.6	5.78	160.9	8.68	197.2	11.84	239.4	15.33	273.9	1.258	0.252
1635	24.8	153.8	7.95	15.7	127.2	3.67	133.5	124.1	1.119	8017	3.40	126.5	5.76	161.0	8.68	197.2	11.83	239.3	15.32	273.8	1.257	0.252
1640	24.8	153.9	8.45	15.6	127.2	3.67	126.5	124.2	1.162	8019	3.41	126.5	5.78	161.0	8.68	197.2	11.85	239.4	15.35	273.8	1.259	0.252
1645	24.7	153.8	8.37	15.3	127.4	3.68	126.8	124.1	1.062	8017	3.41	126.3	5.77	160.7	8.69	197.1	11.85	239.2	15.36	273.4	1.260	0.252
1650	24.6	153.8	8.70	15.2	127.4	3.67	126.3	124.1	1.224	8017	3.43	126.5	5.78	160.9	8.67	197.1	11.83	239.0	15.33	273.3	1.258	0.252
1656	24.7	153.6	9.31	15.0	127.2	3.67	126.3	124.1	1.152	8017	3.43	126.6	5.78	161.5	8.67	197.2	11.82	239.4	15.29	273.5	1.252	0.252
1661	24.5	153.6	9.82	15.0	127.4	3.68	127.2	124.1	1.108	8017	3.42	126.5	5.78	161.9	8.68	197.8	11.82	239.7	15.30	273.8	1.251	0.252
1666	24.7	153.6	11.53	15.4	127.2	3.67	128.6	124.1	1.059	8017	3.43	126.3	5.79	161.5	8.68	197.6	11.83	239.6	15.34	273.7	1.253	0.252
1671	24.7	153.6	9.31	15.5	127.2	3.67	130.1	124.1	1.224	8017	3.42	126.3	5.77	161.5	8.66	197.6	11.80	239.4	15.31	273.4	1.252	0.252
1676	24.6	153.8	7.85	15.4	127.2	3.68	130.8	124.1	1.203	8017	3.43	126.5	5.78	161.9	8.67	197.9	11.81	239.6	15.29	273.7	1.248	0.251
1681	24.6	153.8	8.91	15.2	127.2	3.68	131.0	124.2	1.244	8017	3.43	126.5	5.78	162.3	8.67	198.2	11.81	239.9	15.30	273.8	1.246	0.252
1686	24.6	153.9	9.19	15.1	127.4	3.68	125.9	124.2	1.218	8019	3.44	126.5	5.79	162.4	8.66	198.2	11.80	240.2	15.30	273.9	1.245	0.252
1691	24.5	153.8	9.60	15.4	127.2	3.68	125.9	124.1	1.217	8019	3.44	126.6	5.79	162.9	8.67	198.7	11.80	240.2	15.29	274.0	1.244	0.251
1696	24.5	153.6	10.41	15.3	127.5	3.68	125.9	124.1	1.225	8017	3.43	126.6	5.77	163.0	8.66	198.8	11.78	240.6	15.26	274.3	1.239	0.251

TABLE A1.-Continued

Time	PT1	SD1	FM2	PT6	SD6B	PT5B	SD5A	SD5B	FM3	VFD3C	PT10	SD10	PT11	SD11	PT12	SD12	PT13	SD13	PT14	SD14	FM4C	FM5
(sec)	(psia)	(R)	(lb/s)	(psia)	(R)	(psia)	(R)	(R)	(lb/s)	(rpm)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(lb/s)	(lb/s)
1701	24.6	153.6	10.02	15.2	127.4	3.68	128.6	124.1	1.229	8019	3.44	126.5	5.78	163.1	8.66	199.1	11.78	240.9	15.27	274.4	1.238	0.251
1706	24.5	153.5	8.35	15.3	127.2	3.68	131.0	124.2	1.217	8016	3.44	126.5	5.76	163.6	8.65	199.4	11.77	241.0	15.24	274.6	1.235	0.251
1711	24.5	153.5	8.53	14.8	127.2	3.68	131.0	124.1	1.212	8016	3.44	126.6	5.79	163.4	8.68	199.5	11.80	241.1	15.27	274.6	1.236	0.251
1716	24.5	153.5	9.11	14.6	127.4	3.68	131.3	124.1	1.245	8017	3.45	126.5	5.78	163.1	8.67	199.4	11.79	240.9	15.27	274.4	1.236	0.251
1721	24.4	153.5	9.49	15.0	127.4	3.68	131.4	124.1	1.217	8016	3.44	126.3	5.78	163.4	8.67	199.5	11.80	241.0	15.26	274.4	1.233	0.251
1726	24.4	153.5	10.21	15.1	127.4	3.68	131.4	124.2	1.241	8016	3.44	126.5	5.78	163.6	8.66	199.7	11.78	241.2	15.25	274.7	1.231	0.251
1731	24.4	153.6	10.22	15.2	127.4	3.68	131.6	124.2	1.210	8019	3.45	126.5	5.79	163.7	8.67	199.9	11.79	241.5	15.28	274.8	1.232	0.251
1736	24.2	153.5	9.59	15.5	127.4	3.69	131.4	124.2	1.217	8017	3.45	126.5	5.78	163.9	8.67	200.1	11.81	241.6	15.25	274.8	1.229	0.251
1741	24.3	153.6	8.11	15.1	127.4	3.68	131.7	124.2	1.234	8019	3.45	126.8	5.79	164.0	8.67	200.3	11.79	241.8	15.26	275.1	1.227	0.251
1746	24.2	153.5	9.26	15.0	127.4	3.69	131.6	124.4	1.230	8019	3.45	126.5	5.78	164.1	8.67	200.5	11.79	241.9	15.25	275.3	1.225	0.251
1751	24.2	153.3	10.03	15.3	127.2	3.68	131.6	124.2	1.213	8019	3.45	126.6	5.78	164.3	8.67	200.6	11.77	242.0	15.25	275.3	1.223	0.251
1756	24.2	153.3	9.43	15.4	127.2	3.69	131.6	124.2	1.249	8017	3.44	126.5	5.78	164.3	8.68	200.9	11.80	242.1	15.26	275.6	1.222	0.251
1761	24.2	153.3	8.56	15.7	127.4	3.68	131.9	124.1	1.227	8016	3.45	126.5	5.79	164.1	8.68	200.9	11.80	242.1	15.25	275.4	1.221	0.251
1766	24.4	153.2	8.90	15.4	127.4	3.69	131.7	123.9	1.240	8019	3.46	126.5	5.80	164.0	8.68	200.7	11.80	242.0	15.27	275.2	1.224	0.251
1771	24.3	153.3	9.05	15.3	127.2	3.69	131.6	123.9	1.209	8017	3.45	126.5	5.80	163.9	8.68	200.6	11.80	242.0	15.27	275.2	1.221	0.251
1776	24.1	153.3	9.75	15.1	127.4	3.69	131.9	124.1	1.207	8017	3.45	126.5	5.79	164.1	8.68	200.6	11.79	242.0	15.25	275.2	1.219	0.251
1781	23.9	153.3	10.35	14.9	127.4	3.69	132.0	124.1	1.157	8017	3.45	126.5	5.80	164.3	8.68	200.9	11.80	242.1	15.24	275.4	1.217	0.251
1786	24.1	153.5	10.58	14.6	127.4	3.69	131.9	124.1	1.142	8019	3.45	126.5	5.80	164.1	8.68	200.7	11.81	242.3	15.24	275.4	1.215	0.251
1791	24.0	153.3	7.47	14.9	127.5	3.68	132.0	124.2	1.195	8016	3.46	126.6	5.79	164.4	8.67	201.0	11.80	242.4	15.24	275.6	1.214	0.251
1796	23.9	153.5	8.88	14.6	127.4	3.69	132.2	124.2	1.150	8017	3.46	126.5	5.81	164.7	8.69	201.3	11.80	242.7	15.24	275.9	1.211	0.251
1801	24.0	153.3	10.40	14.6	127.4	3.68	132.0	124.2	1.149	8019	3.45	126.6	5.78	164.8	8.68	201.5	11.80	242.8	15.23	275.9	1.210	0.250
1806	24.0	153.3	10.78	14.9	127.5	3.68	132.0	124.2	1.261	8019	3.45	126.6	5.79	164.8	8.69	201.5	11.79	242.9	15.22	276.1	1.208	0.250
1811	23.8	153.2	6.70	15.0	127.4	3.68	131.0	124.2	1.258	8017	3.46	126.6	5.80	164.8	8.70	201.7	11.80	243.1	15.24	276.2	1.208	0.250
1816	24.0	153.3	8.96	14.8	127.4	3.68	131.9	124.2	1.228	8017	3.45	126.5	5.79	164.7	8.68	201.5	11.79	242.9	15.25	276.1	1.208	0.250
1821	24.0	153.2	9.77	14.9	127.4	3.68	131.9	124.2	1.247	8016	3.46	126.5	5.80	164.8	8.69	201.7	11.79	242.9	15.24	276.1	1.207	0.250
1826	24.0	153.2	9.89	15.1	127.2	3.70	131.9	124.2	1.225	8016	3.46	126.6	5.80	164.8	8.69	201.7	11.81	242.9	15.26	276.2	1.207	0.251
1830	23.9	153.2	8.26	15.0	127.4	3.69	132.0	124.2	1.247	8019	3.46	126.5	5.81	164.8	8.68	201.8	11.78	243.1	15.24	276.2	1.204	0.250
1835	23.9	153.2	9.39	15.0	127.4	3.68	131.9	124.2	1.260	8017	3.45	126.5	5.79	164.8	8.68	201.8	11.79	243.1	15.24	276.3	1.203	0.250
1840	24.1	153.2	9.97	15.0	127.4	3.69	132.0	124.2	1.253	8017	3.46	126.6	5.81	164.8	8.69	201.7	11.80	243.1	15.25	276.2	1.204	0.250
1845	23.9	153.2	7.13	15.5	127.2	3.68	131.9	124.2	1.188	8017	3.46	126.6	5.80	164.7	8.68	201.8	11.80	243.2	15.25	276.2	1.202	0.250
1850	24.1	153.2	9.04	15.7	127.2	3.68	131.9	124.1	1.269	8017	3.45	126.5	5.80	165.0	8.68	201.8	11.78	243.3	15.21	276.3	1.198	0.250
1855	24.0	153.0	10.12	15.1	127.4	3.68	132.0	124.1	1.304	8016	3.46	126.5	5.81	165.1	8.70	202.1	11.80	243.4	15.21	276.5	1.196	0.250
1860	24.0	152.9	9.49	15.1	126.9	3.68	131.9	123.9	1.200	8019	3.45	126.5	5.78	165.3	8.67	202.1	11.77	243.6	15.18	276.6	1.192	0.250
1865	24.0	153.0	8.06	14.9	127.1	3.69	131.7	123.9	1.253	8017	3.47	126.3	5.81	165.4	8.69	202.3	11.79	243.8	15.21	276.8	1.193	0.250

TABLE A1.-Continued

Time	PT1	SD1	FM2	PT6	SD6B	PT5B	SD5A	SD5B	FM3	VFD3C	PT10	SD10	PT11	SD11	PT12	SD12	PT13	SD13	PT14	SD14	FM4C	FM5
(sec)	(psia)	(R)	(lb/s)	(psia)	(R)	(psia)	(R)	(R)	(lb/s)	(rpm)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(lb/s)	(lb/s)
1870	24.1	153.2	10.15	15.2	127.2	3.69	131.9	123.9	1.278	8017	3.46	126.3	5.79	165.4	8.68	202.5	11.78	243.8	15.19	277.0	1.190	0.250
1875	24.0	153.2	10.85	15.3	127.2	3.70	132.2	123.9	1.294	8016	3.46	126.5	5.80	165.4	8.69	202.6	11.79	244.1	15.19	277.1	1.189	0.250
1880	24.1	153.2	8.94	15.2	127.2	3.71	132.2	124.1	1.268	8016	3.47	126.5	5.81	165.1	8.70	202.5	11.79	244.0	15.24	277.0	1.192	0.250
1885	24.1	153.3	8.10	15.2	127.4	3.70	132.3	124.2	1.246	8014	3.47	126.5	5.80	165.1	8.68	202.6	11.79	244.0	15.22	277.0	1.190	0.250
1890	24.1	153.3	9.76	14.8	127.4	3.71	132.2	124.2	1.239	8016	3.44	126.5	5.79	165.1	8.67	202.6	11.78	244.0	15.18	277.0	1.186	0.250
1895	23.8	153.3	9.73	14.7	127.5	3.71	126.0	124.2	1.203	8017	3.45	126.6	5.80	165.4	8.69	202.9	11.78	244.2	15.19	277.2	1.184	0.249
1900	23.9	153.3	10.38	15.0	127.4	3.72	129.3	124.2	1.268	8019	3.45	126.8	5.79	165.4	8.68	203.0	11.77	244.5	15.16	277.5	1.180	0.249
1905	23.9	153.3	6.68	15.1	127.4	3.72	132.2	124.2	1.203	8017	3.46	126.8	5.80	165.7	8.69	203.3	11.77	244.9	15.18	277.7	1.179	0.249
1910	23.8	153.3	9.27	15.1	127.4	3.72	132.3	124.4	1.245	8016	3.46	126.6	5.81	166.0	8.70	203.4	11.79	245.0	15.18	277.8	1.178	0.249
1915	23.7	153.3	10.57	14.8	127.4	3.71	132.5	124.4	1.230	8017	3.46	126.6	5.80	166.0	8.68	203.7	11.76	245.3	15.16	278.1	1.174	0.249
1920	23.8	153.2	7.77	15.1	127.4	3.72	132.5	124.2	1.216	8019	3.47	126.6	5.81	166.3	8.69	203.8	11.77	245.5	15.19	278.4	1.175	0.249
1925	23.8	153.2	9.71	15.0	127.4	3.73	126.6	124.2	1.265	8016	3.47	126.8	5.81	166.4	8.70	203.8	11.79	245.5	15.17	278.4	1.172	0.249
1930	23.9	153.0	10.26	15.3	127.5	3.73	131.9	124.2	1.288	8016	3.47	126.6	5.81	166.4	8.70	204.0	11.78	245.8	15.18	278.6	1.171	0.249
1935	24.0	153.0	7.72	15.6	127.4	3.73	132.0	124.2	1.283	8017	3.47	126.6	5.81	166.3	8.70	204.0	11.77	245.5	15.16	278.5	1.170	0.249
1940	24.0	152.9	7.77	15.2	127.4	3.73	132.5	124.2	1.271	8016	3.48	126.5	5.82	166.3	8.71	204.0	11.79	245.5	15.18	278.5	1.171	0.249
1945	23.9	153.2	9.45	15.1	127.4	3.73	132.3	124.2	1.249	8016	3.47	126.5	5.81	166.3	8.70	204.0	11.78	245.4	15.18	278.4	1.170	0.249
1950	23.8	153.0	10.18	14.8	127.5	3.73	128.6	124.2	1.234	8014	3.48	126.5	5.83	166.0	8.72	203.8	11.81	245.4	15.21	278.4	1.171	0.250
1955	23.9	153.3	9.41	14.8	127.5	3.73	128.3	124.4	1.212	8019	3.48	126.8	5.82	166.0	8.71	203.7	11.81	245.4	15.20	278.5	1.170	0.249
1960	23.8	153.2	7.89	15.0	127.5	3.73	131.0	124.4	1.220	8017	3.44	126.6	5.80	166.0	8.68	203.8	11.77	245.5	15.17	278.5	1.166	0.249
1965	23.7	153.5	9.13	14.9	127.5	3.74	132.0	124.5	1.223	8017	3.48	126.8	5.83	165.7	8.73	203.7	11.84	245.3	15.24	278.4	1.171	0.250
1970	23.7	153.2	10.35	14.9	127.7	3.73	132.3	124.4	1.140	8019	3.47	126.8	5.82	165.7	8.70	203.6	11.78	245.1	15.20	278.2	1.168	0.249
1975	23.8	153.2	7.12	15.1	127.7	3.73	132.5	124.4	1.126	8019	3.47	126.8	5.81	166.0	8.70	203.6	11.77	245.4	15.18	278.5	1.165	0.249
1980	23.6	153.0	8.16	15.1	127.5	3.73	132.2	124.4	1.276	8016	3.46	126.6	5.83	166.0	8.72	203.6	11.81	245.4	15.21	278.5	1.165	0.249
1985	23.9	153.0	10.18	15.1	127.5	3.73	132.5	124.2	1.240	8016	3.46	126.5	5.83	165.6	8.72	203.4	11.83	245.1	15.26	278.4	1.169	0.250
1990	23.9	153.0	9.09	15.2	127.4	3.74	132.5	124.2	1.282	8016	3.43	126.5	5.79	165.3	8.68	203.3	11.78	244.7	15.17	278.0	1.163	0.249
1995	23.8	153.2	7.55	14.8	127.5	3.76	132.8	124.4	1.253	8014	3.45	126.6	5.81	165.4	8.70	203.3	11.78	245.1	15.16	278.4	1.159	0.249
2000	24.0	153.2	9.89	14.9	127.5	3.76	132.6	124.4	1.212	8016	3.45	126.5	5.81	165.7	8.70	203.6	11.79	245.5	15.16	278.7	1.158	0.249
2005	23.8	153.2	9.87	15.1	127.5	3.77	132.8	124.4	1.203	8017	3.44	126.6	5.81	165.7	8.71	203.8	11.79	245.6	15.17	278.9	1.156	0.249
2010	23.8	153.2	7.05	15.0	127.5	3.77	132.8	124.2	1.225	8019	3.46	126.5	5.81	165.7	8.70	204.0	11.78	245.8	15.18	278.9	1.157	0.249
2015	23.7	153.3	7.46	15.0	127.7	3.77	132.9	124.4	1.167	8017	3.45	126.8	5.80	166.0	8.69	204.0	11.78	245.8	15.16	279.0	1.154	0.249
2020	23.6	153.5	9.35	14.9	127.5	3.78	132.9	124.5	1.178	8017	3.46	126.6	5.82	166.0	8.71	204.0	11.80	245.9	15.19	279.1	1.154	0.249
2025	23.7	153.2	8.99	15.2	127.7	3.77	132.8	124.4	1.257	8017	3.46	126.8	5.81	166.0	8.70	204.1	11.79	245.9	15.18	279.1	1.153	0.249
2030	23.8	153.3	7.92	15.1	127.8	3.76	132.9	124.5	1.281	8115	3.44	126.6	5.78	166.1	8.68	204.1	11.79	246.0	15.22	279.2	1.155	0.249
2035	23.8	153.3	9.20	14.8	128.0	3.72	132.9	124.7	1.246	8320	3.33	126.5	5.64	166.7	8.53	204.2	11.71	246.0	15.35	279.2	1.164	0.251

TABLE A1.-Continued

Time	PT1	SD1	FM2	PT6	SD6B	PT5B	SD5A	SD5B	FM3	VFD3C	PT10	SD10	PT11	SD11	PT12	SD12	PT13	SD13	PT14	SD14	FM4C	FM5
(sec)	(psia)	(R)	(lb/s)	(psia)	(R)	(psia)	(R)	(R)	(lb/s)	(rpm)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(lb/s)	(lb/s)
2040	23.9	153.6	9.54	15.1	128.1	3.68	133.2	124.7	1.233	8619	3.21	126.2	5.46	167.2	8.40	204.5	11.64	246.3	15.44	279.6	1.168	0.252
2045	23.7	153.5	8.00	15.1	128.1	3.63	133.4	124.5	1.187	8720	3.15	126.0	5.36	167.8	8.33	205.2	11.59	246.8	15.49	280.3	1.168	0.252
2050	23.6	153.3	8.89	15.0	128.0	3.61	132.8	124.4	1.209	8720	3.09	125.7	5.31	168.4	8.28	206.0	11.57	247.4	15.47	281.4	1.161	0.252
2055	23.6	153.5	10.58	14.8	128.0	3.58	133.2	124.4	1.296	8718	3.11	125.7	5.33	167.7	8.32	206.1	11.59	247.7	15.48	281.8	1.159	0.251
2060	24.1	153.6	7.59	14.7	127.8	3.54	133.1	124.5	1.303	8720	3.09	124.8	5.31	167.4	8.29	206.1	11.57	247.6	15.44	281.9	1.155	0.251
2065	23.9	153.6	9.00	15.0	128.0	3.53	133.2	124.4	1.291	8721	3.08	125.0	5.29	167.7	8.25	206.4	11.54	248.1	15.43	282.6	1.150	0.251
2070	23.8	153.8	10.22	15.4	127.8	3.51	133.4	124.2	1.240	8720	3.04	124.8	5.26	168.1	8.21	206.8	11.52	248.5	15.39	283.0	1.145	0.250
2075	23.7	153.6	7.11	15.4	127.7	3.49	133.4	124.2	1.207	8721	3.05	125.0	5.26	167.9	8.22	206.9	11.53	248.9	15.41	283.5	1.143	0.250
2080	23.6	153.8	8.14	15.2	127.7	3.47	133.2	124.1	1.150	8721	3.03	125.3	5.24	168.2	8.19	207.2	11.49	249.3	15.37	283.9	1.137	0.250
2085	23.6	153.6	8.98	14.8	127.5	3.45	133.2	123.9	1.280	8720	3.02	125.3	5.23	168.2	8.19	207.3	11.48	249.5	15.35	284.3	1.134	0.249
2090	23.6	153.5	9.95	14.9	127.4	3.44	133.1	123.9	1.282	8720	3.01	125.3	5.23	168.5	8.18	207.4	11.48	250.0	15.34	284.7	1.131	0.249
2095	23.7	153.5	7.82	14.9	127.4	3.44	133.1	123.8	1.300	8721	3.00	125.0	5.24	168.4	8.21	207.6	11.51	250.3	15.36	285.0	1.131	0.249
2100	23.7	153.5	9.64	15.1	127.2	3.42	133.2	123.8	1.280	8721	3.00	125.3	5.24	167.8	8.21	207.3	11.52	250.0	15.37	284.9	1.131	0.249
2105	24.0	153.3	9.60	14.9	127.2	3.40	133.1	123.6	1.219	8720	2.97	125.0	5.21	167.7	8.18	207.0	11.48	250.2	15.34	285.2	1.127	0.249
2110	23.7	153.3	7.55	15.1	127.2	3.39	132.9	123.6	1.192	8720	2.98	124.8	5.22	167.5	8.16	207.2	11.46	250.2	15.31	285.3	1.124	0.248
2115	23.6	153.2	10.31	14.8	127.1	3.38	132.9	123.5	1.206	8720	2.97	125.0	5.21	167.9	8.15	207.3	11.45	250.4	15.29	285.7	1.119	0.248
2120	23.6	153.3	8.94	15.2	126.9	3.38	132.9	123.5	1.261	8720	2.97	124.7	5.21	168.1	8.18	207.4	11.47	250.7	15.29	285.9	1.118	0.248
2125	23.8	153.3	8.35	15.2	126.8	3.37	131.4	123.3	1.280	8721	2.96	124.7	5.21	168.1	8.16	207.4	11.45	250.8	15.28	286.1	1.115	0.248
2130	23.7	150.0	9.30	15.0	123.9	4.35	131.6	121.8	1.255	7361	4.35	132.2	5.91	168.8	7.89	207.7	10.11	249.3	12.49	285.7	0.912	0.211
2135	23.6	150.2	8.59	15.0	124.2	4.81	136.3	122.3	1.183	7422	4.80	145.5	6.23	173.8	8.05	211.6	9.96	251.8	11.93	287.3	0.865	0.199
2140	23.5	152.8	8.25	15.1	126.6	4.43	140.6	123.6	1.316	7515	4.15	151.2	6.35	176.9	8.87	214.0	11.36	254.3	14.00	287.9	1.013	0.225
2145	23.7	153.0	10.31	14.9	127.2	3.96	135.3	124.4	1.317	7918	3.69	140.6	6.12	175.1	8.99	213.4	11.98	253.8	15.21	286.9	1.103	0.244
2150	23.7	153.0	9.29	15.2	127.4	3.89	133.5	124.7	1.258	7917	3.61	134.4	6.03	172.6	8.90	211.8	11.92	252.7	15.20	285.9	1.106	0.245
2155	23.6	153.2	7.82	15.1	127.4	3.87	133.4	124.7	1.200	7918	3.59	127.2	6.00	170.6	8.88	210.6	11.92	252.2	15.22	285.6	1.107	0.246
2160	23.5	153.3	9.01	14.9	127.7	3.87	133.2	124.7	1.397	7917	3.58	126.9	5.99	169.5	8.89	209.7	11.92	251.6	15.23	285.2	1.110	0.247
2165	23.6	153.2	10.50	15.0	127.8	3.86	133.2	124.8	1.366	7917	3.56	126.9	5.97	168.6	8.86	208.9	11.91	251.1	15.25	284.8	1.111	0.247
2170	23.7	153.2	7.59	14.9	127.8	3.84	133.2	124.7	1.375	8017	3.52	126.8	5.92	167.8	8.83	208.1	11.89	250.5	15.27	284.3	1.114	0.248
2175	23.7	153.0	9.22	15.1	127.8	3.83	133.5	124.7	1.318	8017	3.52	126.8	5.91	167.5	8.82	207.6	11.89	250.2	15.24	283.9	1.113	0.248
2180	23.7	153.0	7.14	15.3	127.8	3.82	133.4	124.5	1.292	8019	3.51	126.8	5.91	167.2	8.81	207.0	11.89	249.8	15.23	283.7	1.111	0.248
2185	23.7	153.0	8.24	15.2	127.8	3.82	133.5	124.7	1.340	8017	3.52	126.6	5.91	167.4	8.81	207.0	11.88	249.8	15.21	283.7	1.110	0.248
2190	23.7	153.0	10.37	15.2	127.8	3.82	133.5	124.5	1.274	8017	3.51	126.5	5.90	167.2	8.80	206.8	11.87	249.6	15.22	283.7	1.109	0.248
2195	23.7	153.0	6.88	14.8	127.8	3.83	133.2	124.7	1.266	8017	3.51	126.5	5.92	167.1	8.83	206.8	11.91	249.6	15.25	283.4	1.112	0.248
2200	23.5	152.9	10.08	15.0	127.8	3.82	133.2	124.5	1.228	8016	3.51	126.5	5.90	167.0	8.81	206.5	11.89	249.1	15.23	283.2	1.111	0.248
2205	23.4	152.9	8.83	15.2	127.7	3.82	133.4	124.7	1.194	8016	3.51	126.5	5.90	166.8	8.81	206.2	11.87	249.1	15.23	283.0	1.110	0.248

TABLE A1.-Continued

Time	PT1	SD1	FM2	PT6	SD6B	PT5B	SD5A	SD5B	FM3	VFD3C	PT10	SD10	PT11	SD11	PT12	SD12	PT13	SD13	PT14	SD14	FM4C	FM5
(sec)	(psia)	(R)	(lb/s)	(psia)	(R)	(psia)	(R)	(R)	(lb/s)	(rpm)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(lb/s)	(lb/s)
2210	23.4	152.6	8.36	15.2	127.7	3.81	133.5	124.5	1.187	8016	3.51	126.3	5.89	167.0	8.79	206.2	11.85	249.0	15.22	283.0	1.109	0.248
2215	23.5	152.8	9.87	15.0	127.7	3.82	133.4	124.4	1.183	8017	3.51	126.3	5.91	167.0	8.81	206.2	11.89	249.0	15.24	283.0	1.110	0.248
2220	23.4	152.9	8.66	15.2	127.7	3.82	133.4	124.4	1.129	8016	3.50	126.3	5.90	166.8	8.81	206.0	11.89	249.0	15.22	282.8	1.108	0.248
2225	23.4	152.9	8.71	15.1	127.7	3.81	133.4	124.5	1.190	8017	3.50	126.3	5.89	166.7	8.79	205.8	11.87	248.6	15.21	282.6	1.107	0.248
2230	23.2	152.9	10.27	15.2	127.8	3.81	132.5	124.5	1.353	8016	3.50	126.6	5.88	166.5	8.79	205.7	11.86	248.5	15.23	282.5	1.108	0.248
2235	23.4	152.9	6.62	15.2	128.0	3.80	133.1	124.7	1.401	8016	3.50	126.5	5.88	166.5	8.78	205.6	11.85	248.4	15.20	282.4	1.106	0.248
2240	23.3	153.0	9.98	15.1	127.8	3.81	132.9	124.7	1.400	8016	3.50	126.5	5.89	166.5	8.80	205.6	11.88	248.5	15.21	282.4	1.105	0.248
2245	23.3	153.0	9.79	15.0	127.8	3.80	132.9	124.5	1.399	8017	3.50	126.3	5.87	166.7	8.77	205.7	11.85	248.4	15.20	282.4	1.104	0.248
2250	23.7	153.0	9.35	15.0	127.8	3.80	133.1	124.7	1.364	8017	3.50	126.6	5.88	166.8	8.78	205.7	11.85	248.6	15.20	282.4	1.103	0.248
2255	23.6	153.0	9.83	15.1	127.8	3.79	133.1	124.5	1.348	8017	3.50	126.6	5.88	166.8	8.78	205.8	11.84	248.6	15.20	282.5	1.101	0.248
2260	23.7	153.2	8.08	14.9	127.8	3.80	133.1	124.7	1.269	8017	3.50	126.8	5.88	167.0	8.78	205.8	11.86	248.6	15.22	282.5	1.103	0.248
2265	23.6	153.0	10.02	14.8	128.0	3.79	133.2	124.7	1.236	8019	3.49	126.9	5.87	167.1	8.76	206.0	11.84	248.7	15.20	282.5	1.100	0.248
2270	23.4	153.0	7.22	15.1	127.8	3.80	133.1	124.5	1.274	8019	3.51	126.8	5.89	167.2	8.78	206.1	11.85	248.7	15.22	282.8	1.100	0.248
2275	23.5	147.4	9.46	15.2	122.6	5.16	132.6	121.3	1.401	0	5.13	141.3	6.34	169.8	7.81	207.2	9.26	245.3	10.77	282.3	0.779	0.181
2280	23.7	147.3	9.84	15.3	122.6	5.70	136.2	121.6	1.375	0	5.67	151.9	6.53	175.2	7.54	211.3	8.53	247.8	9.54	285.2	0.683	0.000
2285	23.7	147.3	7.11	15.4	123.2	6.02	136.8	122.6	1.299	0	5.99	154.9	6.79	178.5	7.69	214.6	8.57	250.2	8.94	289.5	0.629	0.000
2290	23.7	147.1	9.65	15.3	123.5	6.43	138.5	123.3	1.277	0	6.39	161.2	6.98	180.4	7.66	216.0	8.12	251.2	8.68	293.7	0.602	0.000
2296	23.7	147.3	6.51	15.1	123.9	6.77	141.5	124.1	1.304	0	6.68	164.7	7.18	182.1	7.78	217.0	8.24	251.7	8.72	296.0	0.600	0.000
2301	23.5	147.3	9.51	15.2	124.5	7.11	141.9	124.7	1.231	0	7.05	165.4	7.39	182.6	7.90	217.3	8.26	252.1	8.65	296.9	0.430	0.000
2306	23.6	147.3	6.78	15.0	125.4	7.30	140.6	125.0	1.149	0	7.60	167.5	7.87	182.9	8.33	217.4	8.66	252.2	9.00	297.0	0.423	0.000
2311	23.3	147.4	9.56	15.3	126.3	7.50	142.3	125.6	1.408	0	8.15	168.5	8.31	183.5	8.63	218.1	8.88	252.9	9.10	296.1	0.431	0.000
2316	23.6	147.4	10.04	15.5	127.1	7.71	138.8	125.9	1.390	0	8.56	168.6	8.68	183.6	8.94	218.7	9.17	253.5	9.37	295.2	0.445	0.000
2321	23.8	147.4	6.89	15.3	127.4	7.92	139.0	126.2	1.314	0	8.75	168.8	8.90	183.7	9.20	219.4	9.51	254.1	9.76	294.3	0.466	0.000
2326	23.6	147.4	9.13	15.1	127.7	8.15	139.3	126.3	1.270	0	9.24	168.9	9.33	184.6	9.53	220.2	9.76	254.7	9.95	293.7	0.475	0.000
2331	23.4	147.4	9.76	15.6	128.3	8.35	140.0	126.6	1.142	0	9.59	169.5	9.65	185.1	9.84	221.0	10.03	255.4	10.20	293.5	0.488	0.000
2336	23.5	147.4	6.92	15.2	128.7	8.58	140.9	126.9	1.406	0	9.85	170.3	9.92	185.8	10.11	221.6	10.32	255.9	10.51	293.3	0.504	0.000
2341	23.5	147.4	9.56	14.9	129.0	8.80	142.8	127.2	1.398	0	10.21	171.0	10.25	186.9	10.40	222.2	10.54	256.6	10.68	293.5	0.012	0.000
2346	23.5	147.4	10.26	16.0	129.3	9.02	141.3	127.4	1.369	0	10.58	171.4	10.62	188.0	10.75	222.7	10.90	257.1	11.02	293.7	0.012	0.000
2351	23.6	147.4	7.96	15.1	129.8	9.24	139.4	127.7	1.309	0	10.91	170.6	10.93	189.2	11.07	223.3	11.19	257.3	11.30	294.5	0.012	0.000
2356	23.5	147.4	9.87	15.2	130.1	9.48	139.4	127.7	1.263	0	11.18	170.7	11.19	190.2	11.31	223.9	11.42	257.5	11.51	295.2	0.013	0.000
2361	23.4	147.3	7.38	15.1	130.1	9.69	141.0	128.1	1.160	0	11.45	172.7	11.46	191.5	11.57	224.4	11.68	257.9	11.76	296.1	0.013	0.000
2366	23.5	147.3	9.14	15.1	130.5	9.92	141.3	128.4	1.404	0	11.75	175.2	11.75	192.3	11.86	224.9	11.96	258.2	12.03	297.0	0.013	0.000
2401	23.8	147.3	9.38	15.3	132.3	11.57	148.7	130.5	1.366	0	13.46	195.9	13.44	197.5	13.52	229.4	13.60	261.3	13.63	303.9	0.016	0.000

TABLE A2.-LIQUID HYDROGEN DESIFICATION TEST NO. H1 DATA.

Time	PT1	SD1	FM2	PT6	SD6B	PT5B	SD5A	SD5B	FM3	VFD3C	PT10	SD10	PT11	SD11	PT12	SD12	PT13	SD13	PT14	SD14	FM4C	FM5
(sec)	(psia)	(R)	(lb/s)	(psia)	(R)	(psia)	(R)	(R)	(lb/s)	(rpm)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(lb/s)	(lb/s)
101	32.3	40.3	1.834	29.7	37.4	15.37	39.2	37.1	0.156	0	15.17	40.7	15.24	64.6	15.20	93.6	15.11	114.6	14.95	128.4	0.150	0.000
106	32.4	40.3	1.886	29.4	37.3	15.34	39.2	37.1	0.169	0	15.15	40.8	15.22	64.9	15.18	93.7	15.10	114.8	14.94	128.6	0.146	0.000
111	32.5	40.4	1.949	29.9	37.3	15.35	39.2	37.1	0.166	0	15.15	40.8	15.22	65.0	15.19	94.1	15.11	115.1	14.95	129.0	0.142	0.000
116	32.7	40.4	1.958	29.6	37.3	15.35	39.3	37.1	0.204	0	15.16	40.9	15.22	65.0	15.19	94.2	15.11	115.2	14.96	128.9	0.140	0.000
121	32.8	40.4	1.970	29.7	37.3	15.33	39.3	37.1	0.174	0	15.14	40.8	15.21	65.0	15.18	94.2	15.11	115.2	14.95	129.0	0.140	0.000
126	33.2	40.4	1.987	30.0	37.3	15.37	39.3	37.1	0.162	0	15.18	40.9	15.25	64.9	15.21	94.2	15.14	115.2	14.98	129.0	0.140	0.000
130	32.9	40.4	1.965	29.9	37.3	15.36	39.2	37.1	0.212	0	15.17	40.8	15.23	65.0	15.20	94.2	15.12	115.2	14.97	128.9	0.140	0.000
135	33.2	40.3	1.998	30.1	37.3	15.37	39.3	37.1	0.167	0	15.18	40.8	15.25	65.0	15.21	94.2	15.13	115.2	14.97	129.0	0.141	0.000
140	33.4	40.3	2.030	30.1	37.3	15.40	39.3	37.1	0.127	0	15.20	40.8	15.27	65.0	15.24	94.2	15.16	115.2	15.00	129.0	0.141	0.000
145	32.4	40.3	2.258	27.8	37.4	15.39	39.3	37.1	0.163	384	15.20	40.9	15.27	65.0	15.25	94.1	15.17	117.5	15.01	130.1	0.144	0.000
150	32.6	40.1	2.262	28.1	37.4	15.38	39.4	37.1	0.160	486	15.19	40.8	15.27	63.8	15.25	92.6	15.18	116.5	15.01	129.5	0.149	0.000
155	32.6	40.1	2.257	28.1	37.4	15.36	39.4	37.1	0.176	586	15.16	40.7	15.26	64.3	15.24	92.3	15.18	116.0	15.02	129.0	0.152	0.000
160	32.8	40.1	2.268	28.3	37.4	15.31	39.3	37.1	0.112	786	15.11	40.6	15.22	64.0	15.21	91.7	15.16	115.6	15.01	128.6	0.154	0.000
165	32.7	40.1	2.223	28.9	37.4	15.27	39.3	37.1	0.180	987	15.08	40.6	15.20	64.3	15.20	91.3	15.16	114.9	15.02	128.0	0.158	0.000
170	32.8	40.1	2.228	28.5	37.3	15.22	39.3	37.1	0.192	1189	15.02	40.5	15.16	64.9	15.18	91.0	15.15	114.3	15.02	127.4	0.161	0.000
175	32.9	40.1	2.254	28.6	37.3	15.17	39.2	37.1	0.233	1388	14.97	40.5	15.13	65.3	15.16	91.2	15.14	114.0	15.02	126.9	0.162	0.000
180	33.4	40.0	2.292	28.9	37.3	15.11	39.2	37.1	0.117	1589	14.91	40.4	15.09	65.3	15.13	91.3	15.12	113.7	15.02	126.5	0.163	0.000
185	33.2	40.1	2.269	28.8	37.3	15.03	39.2	37.0	0.169	1790	14.84	40.3	15.04	64.7	15.09	91.0	15.10	113.1	15.00	125.9	0.165	0.000
190	33.1	40.0	2.264	28.7	37.2	14.96	39.2	37.0	0.184	1992	14.77	40.2	14.99	64.0	15.06	90.7	15.08	112.8	15.00	125.3	0.167	0.000
195	33.2	40.0	2.246	28.7	37.2	14.97	39.3	37.0	0.229	2194	14.77	40.1	15.01	63.5	15.10	90.1	15.12	112.2	15.04	124.7	0.175	0.000
200	33.4	40.0	2.250	29.0	37.2	14.93	39.3	37.0	0.171	2393	14.74	40.1	15.01	62.9	15.11	89.6	15.14	111.3	15.06	123.9	0.186	0.000
205	33.5	40.0	2.291	28.8	37.2	14.90	39.3	37.0	0.088	2597	14.70	40.0	15.00	62.4	15.12	88.9	15.16	110.2	15.08	123.2	0.196	0.000
210	33.5	40.0	2.287	28.9	37.2	14.86	39.3	36.9	0.180	2715	14.66	39.9	14.99	62.1	15.13	88.3	15.18	109.3	15.10	122.6	0.206	0.008
215	33.4	40.0	2.267	29.0	37.2	14.81	39.2	36.9	0.190	2900	14.61	39.7	14.97	61.8	15.13	87.8	15.20	108.3	15.12	121.8	0.217	0.014
220	33.7	40.0	2.284	29.1	37.2	14.76	39.2	36.9	0.196	3101	14.56	39.6	14.96	61.4	15.14	87.0	15.22	107.7	15.15	121.0	0.229	0.018
225	33.5	40.0	2.256	29.1	37.1	14.72	39.2	36.9	0.172	3303	14.52	39.5	14.96	60.8	15.17	86.3	15.25	106.8	15.18	120.3	0.242	0.022
230	33.6	40.0	2.275	29.1	37.1	14.69	39.2	36.9	0.110	3504	14.49	39.4	14.97	60.4	15.19	85.7	15.30	105.7	15.23	119.4	0.254	0.024
235	33.6	40.0	2.270	29.2	37.1	14.63	39.2	36.9	0.178	3704	14.43	39.3	14.96	59.9	15.21	84.7	15.34	104.9	15.27	118.6	0.267	0.028
240	34.1	40.0	2.113	30.3	37.1	14.53	39.1	36.8	0.206	3907	14.33	39.2	14.90	59.5	15.18	84.1	15.33	104.1	15.28	117.8	0.278	0.030
245	34.2	40.0	2.144	30.4	37.0	14.43	39.1	36.8	0.173	4106	14.22	39.1	14.84	59.1	15.15	83.3	15.32	103.4	15.26	117.2	0.290	0.034
250	34.3	40.1	2.125	30.5	37.0	14.34	39.1	36.8	0.098	4308	14.14	39.0	14.81	58.8	15.16	82.8	15.34	102.7	15.30	116.6	0.303	0.036
255	34.5	40.0	2.134	30.6	37.0	14.27	39.1	36.7	0.144	4509	14.06	38.9	14.78	58.5	15.16	82.3	15.37	102.1	15.33	116.2	0.313	0.040
260	34.3	40.0	2.137	30.5	36.9	14.19	39.2	36.7	0.406	4711	13.99	38.7	14.76	58.1	15.18	81.8	15.40	101.5	15.36	115.4	0.329	0.042
265	34.3	40.1	2.151	30.4	36.9	14.09	39.1	36.7	0.342	4912	13.88	38.7	14.70	57.7	15.16	81.3	15.41	100.9	15.38	115.1	0.341	0.044

TABLE A2.-Continued.

Time (sec)	PT1 (psia)	SD1 (R)	FM2 (lb/s)	PT6 (psia)	SD6B (R)	PT5B (psia)	SD5A (R)	SD5B (R)	FM3 (lb/s)	VFD3C (rpm)	PT10 (psia)	SD10 (R)	PT11 (psia)	SD11 (R)	PT12 (psia)	SD12 (R)	PT13 (psia)	SD13 (R)	PT14 (psia)	SD14 (R)	FM4C (lb/s)	FM5 (lb/s)
270	34.3	40.0	2.109	30.4	36.9	13.98	39.0	36.6	0.316	5113	13.77	38.5	14.66	57.4	15.15	80.6	15.43	100.4	15.41	114.5	0.352	0.049
275	34.3	40.0	2.131	30.3	36.8	13.92	38.9	36.6	0.521	5314	13.72	38.4	14.66	57.0	15.20	80.2	15.49	99.6	15.47	113.7	0.368	0.050
280	34.0	39.9	2.112	30.2	36.8	13.82	38.9	36.5	0.521	5514	13.61	38.4	14.62	56.5	15.19	79.3	15.51	98.8	15.50	112.8	0.387	0.053
285	34.1	39.9	2.138	30.1	36.7	13.68	38.8	36.5	0.521	5717	13.47	38.3	14.55	56.4	15.17	78.8	15.52	98.0	15.52	112.2	0.402	0.056
290	34.0	39.9	2.119	30.1	36.7	13.52	38.7	36.4	0.521	5915	13.31	38.2	14.44	56.4	15.10	78.7	15.49	98.0	15.52	112.0	0.408	0.058
295	34.1	39.8	2.157	30.2	36.6	13.37	38.6	36.4	0.521	6117	13.15	38.0	14.35	56.4	15.06	78.5	15.48	97.9	15.53	112.0	0.414	0.062
300	34.0	39.8	2.103	30.0	36.6	13.21	38.6	36.3	0.521	6318	12.99	37.8	14.26	56.1	15.01	78.4	15.47	97.7	15.54	111.9	0.422	0.063
305	34.0	39.8	2.128	30.0	36.5	13.05	38.6	36.3	0.521	6518	12.84	37.8	14.15	56.1	14.95	78.4	15.45	97.5	15.55	111.9	0.428	0.067
310	34.0	39.8	2.158	30.0	36.4	12.89	38.8	36.2	0.521	6719	12.67	37.6	14.06	56.1	14.91	78.4	15.45	97.4	15.57	111.7	0.437	0.068
315	34.0	39.8	2.142	29.9	36.4	12.72	38.4	36.1	0.521	6822	12.51	37.4	13.95	55.9	14.85	78.2	15.42	97.2	15.58	111.6	0.442	0.073
320	33.9	39.8	2.148	29.9	36.3	12.57	38.3	36.0	0.521	7023	12.36	37.2	13.86	55.9	14.80	77.9	15.41	97.1	15.59	111.3	0.449	0.073
325	33.9	39.8	2.149	29.8	36.2	12.39	38.5	36.0	0.521	7324	12.16	37.0	13.76	55.3	14.77	77.5	15.42	96.3	15.62	111.1	0.463	0.078
330	33.7	39.8	2.159	29.5	36.1	12.18	38.1	35.9	0.521	7527	11.96	36.1	13.64	55.0	14.72	76.7	15.42	95.6	15.63	110.6	0.481	0.078
335	33.8	39.8	2.206	29.6	36.1	11.99	38.0	35.8	0.520	7726	11.76	35.8	13.52	54.6	14.65	76.6	15.39	94.9	15.64	110.3	0.491	0.082
340	33.6	39.8	2.183	29.6	36.0	11.80	37.9	35.7	0.520	7927	11.57	35.7	13.44	53.7	14.65	75.9	15.43	94.1	15.69	109.9	0.505	0.085
345	33.6	39.8	2.197	29.5	35.9	11.60	37.9	35.6	0.520	8128	11.37	35.6	13.29	53.5	14.55	75.3	15.38	93.6	15.70	109.4	0.517	0.085
350	33.6	39.8	2.189	29.2	35.8	11.39	37.9	35.5	0.520	8330	11.15	35.5	13.17	53.1	14.48	75.1	15.36	93.3	15.69	109.1	0.527	0.087
355	33.4	39.8	2.189	29.0	35.7	11.16	37.6	35.4	0.520	8531	10.92	35.4	13.11	51.5	14.53	73.5	15.46	92.0	15.79	108.0	0.558	0.092
360	33.2	39.8	2.204	28.8	35.6	10.93	37.7	35.3	0.520	8733	10.68	35.2	12.97	50.8	14.48	72.5	15.47	91.0	15.82	107.2	0.575	0.094
365	33.2	39.8	2.236	28.7	35.5	10.67	37.8	35.2	0.519	8932	10.43	35.1	13.05	48.9	14.90	71.7	15.96	90.4	16.14	106.8	0.599	0.097
370	32.9	39.7	2.251	28.4	35.3	10.25	37.4	35.0	0.519	9233	9.98	34.9	12.72	45.2	14.60	66.7	15.69	85.5	15.85	102.7	0.694	0.100
375	32.8	39.8	2.257	28.2	35.1	9.93	37.4	34.8	0.519	9434	9.66	34.7	12.37	43.4	14.25	64.6	15.47	83.3	15.80	101.0	0.713	0.103
380	32.8	39.7	2.303	27.9	34.9	9.58	37.1	34.6	0.519	9636	9.28	34.5	12.17	39.0	14.42	60.5	15.82	79.5	16.09	97.5	0.780	0.105
385	32.7	39.7	2.337	27.8	34.8	9.28	37.0	34.5	0.518	9837	8.98	34.4	11.85	40.2	13.97	60.7	15.38	79.2	15.88	97.1	0.761	0.106
390	32.6	39.7	2.322	27.6	34.6	8.98	37.0	34.3	0.518	10040	8.68	34.2	11.63	38.4	14.00	59.5	15.49	77.9	15.98	96.0	0.788	0.112
395	32.3	39.7	2.320	27.2	34.5	8.69	37.0	34.1	0.518	10340	8.38	34.0	11.25	35.9	14.03	55.1	15.83	74.3	16.35	92.6	0.868	0.117
400	32.4	39.7	2.338	27.4	34.3	8.32	37.2	33.9	0.518	10740	7.92	33.8	10.69	35.5	13.92	43.1	16.18	63.0	16.87	83.6	1.095	0.126
405	32.2	39.8	2.364	27.1	34.0	7.96	37.1	33.6	0.518	11040	7.56	33.5	10.12	35.1	13.52	36.1	16.86	54.7	17.81	75.4	1.275	0.138
410	32.2	39.7	2.377	27.1	33.8	7.53	36.8	33.4	0.518	11240	7.07	33.2	9.60	34.9	13.08	36.4	15.84	51.0	17.16	70.4	1.302	0.136
415	32.2	39.7	2.384	27.1	33.5	7.23	37.2	33.1	0.518	11450	6.83	33.0	9.49	34.7	12.57	36.7	16.07	51.9	17.61	71.8	1.255	0.138
420	32.9	39.8	2.207	28.8	33.3	6.88	36.6	32.9	0.518	11550	6.40	32.7	8.92	34.5	12.35	35.4	15.71	51.9	17.21	70.7	1.228	0.138
425	32.8	39.8	2.206	28.7	33.1	6.60	36.2	32.6	0.518	11750	6.17	32.5	8.60	34.3	12.12	38.1	15.24	56.0	16.81	74.6	1.111	0.134
430	32.8	39.9	2.208	28.6	32.9	6.38	36.9	32.5	0.518	11850	5.97	32.3	8.59	34.3	11.89	41.1	14.48	59.2	16.05	77.7	1.029	0.130
435	33.7	39.9	1.939	30.8	32.8	6.17	36.2	32.3	0.519	12050	5.77	32.2	8.29	34.1	11.92	40.2	14.83	58.5	16.38	77.7	1.044	0.131

TABLE A2.-Continued.

Time	PT1	SD1	FM2	PT6	SD6B	PT5B	SD5A	SD5B	FM3	VFD3C	PT10	SD10	PT11	SD11	PT12	SD12	PT13	SD13	PT14	SD14	FM4C	FM5
(sec)	(psia)	(R)	(lb/s)	(psia)	(R)	(psia)	(R)	(R)	(lb/s)	(rpm)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(lb/s)	(lb/s)
440	33.6	40.0	1.944	30.7	32.6	5.98	36.4	32.1	0.519	12250	5.59	32.0	8.06	33.9	11.50	39.5	14.67	57.8	16.45	76.9	1.060	0.132
445	33.7	40.0	1.932	30.7	32.4	5.78	31.7	32.0	0.519	12450	5.37	31.8	7.93	33.9	11.50	40.7	14.30	58.8	16.11	77.9	1.023	0.130
450	33.7	40.0	1.937	30.7	32.3	5.61	31.5	31.8	0.519	12650	5.16	31.7	7.73	33.7	11.50	41.0	14.55	58.7	16.35	77.9	1.043	0.131
455	33.6	39.9	1.956	30.7	32.1	5.49	31.4	31.7	0.519	12850	5.03	31.5	7.49	33.5	11.18	37.7	14.77	56.6	16.93	76.1	1.114	0.134
460	33.8	39.9	1.932	30.8	32.0	5.33	31.2	31.5	0.519	13060	4.92	31.4	7.37	33.4	11.18	37.1	14.53	57.4	16.66	76.2	1.112	0.133
465	33.9	39.9	1.975	30.9	31.9	5.18	31.1	31.4	0.519	13160	4.65	31.2	7.27	33.3	11.17	39.8	14.43	59.5	16.56	77.9	1.078	0.131
470	34.0	40.0	1.985	30.9	31.8	5.10	31.1	31.3	0.519	13360	4.61	31.1	6.95	33.2	10.82	37.5	14.53	57.7	16.73	76.7	1.123	0.133
475	33.9	39.9	2.003	30.7	31.7	5.00	34.2	31.2	0.519	13560	4.51	31.0	6.75	33.0	10.58	35.5	14.37	55.3	16.82	74.8	1.158	0.135
480	33.9	40.0	1.972	30.8	31.6	4.89	34.6	31.2	0.520	13660	4.37	30.9	6.63	33.0	10.46	35.6	14.12	52.9	16.71	72.5	1.204	0.136
485	33.9	39.9	1.985	31.0	31.5	4.82	35.0	31.0	0.519	13860	4.32	30.8	6.46	32.8	10.23	35.2	14.27	54.5	17.01	74.3	1.170	0.136
490	33.9	39.9	1.968	30.8	31.3	4.66	33.9	30.9	0.520	14060	4.11	30.7	6.44	32.7	10.35	36.9	13.91	57.8	16.59	76.4	1.123	0.133
495	33.8	39.9	1.986	30.8	31.2	4.57	34.9	30.8	0.519	14160	4.11	30.6	6.55	32.7	10.45	39.5	14.54	59.4	17.08	78.0	1.119	0.134
500	33.8	39.9	1.978	30.7	31.2	4.55	34.3	30.7	0.520	14260	4.06	30.5	6.16	32.6	10.03	37.1	14.31	59.5	17.07	77.5	1.152	0.134
505	33.8	39.9	1.972	30.8	31.1	4.42	34.7	30.6	0.519	14460	3.86	30.4	6.21	32.5	10.24	38.3	14.13	58.8	16.94	77.9	1.132	0.134
510	33.7	40.0	1.985	30.6	31.1	4.37	34.7	30.6	0.519	14660	3.86	30.3	6.08	32.5	10.10	39.3	13.65	59.5	16.41	78.8	1.093	0.131
515	33.8	39.9	1.975	30.7	30.9	4.32	33.5	30.4	0.519	14770	3.76	30.2	5.92	32.3	9.73	38.0	14.16	59.9	17.19	78.4	1.153	0.134
520	33.9	39.9	1.994	30.8	30.9	4.17	34.2	30.4	0.519	14870	3.55	30.1	6.40	32.4	10.26	41.9	13.91	61.0	16.77	80.3	1.093	0.132
525	33.8	39.9	1.996	30.7	30.9	4.15	34.9	30.4	0.519	15070	3.67	30.1	5.91	32.2	10.07	39.5	14.11	60.8	16.90	80.2	1.121	0.132
530	33.9	39.9	1.992	30.8	30.8	4.08	34.8	30.3	0.519	15170	3.56	30.0	5.94	32.4	10.04	45.4	13.58	66.0	16.35	84.7	1.005	0.128
535	33.8	39.9	1.964	30.7	30.7	3.96	34.9	30.2	0.520	15370	3.42	29.9	6.08	32.7	10.15	45.5	13.64	67.1	16.38	85.4	1.036	0.127
540	33.8	39.9	1.957	30.7	30.6	3.97	33.3	30.1	0.520	15470	3.41	29.8	5.63	32.3	9.81	42.4	14.16	64.6	17.19	83.6	1.092	0.131
545	33.9	40.0	1.970	30.8	30.6	3.89	35.2	30.1	0.519	15670	3.36	29.8	5.81	32.4	9.83	47.7	13.33	68.0	16.22	87.0	0.994	0.126
550	33.8	39.9	2.004	30.7	30.5	3.89	35.1	30.0	0.519	15770	3.33	29.7	5.41	31.9	9.58	40.7	13.90	63.3	17.01	83.1	1.131	0.131
555	33.8	39.9	1.966	30.7	30.5	3.78	34.7	29.9	0.520	15970	3.23	29.6	5.38	32.3	9.68	47.3	13.70	68.3	16.73	87.5	0.991	0.104
560	33.9	39.9	1.990	30.7	30.3	3.52	35.2	29.7	0.520	15970	3.06	29.4	5.95	35.6	9.87	55.7	13.25	77.0	16.16	95.2	0.827	0.080
565	33.9	39.9	1.975	30.6	30.0	3.39	34.5	29.5	0.520	16170	2.96	29.2	6.28	38.8	9.81	61.5	13.03	83.6	15.88	101.6	0.731	0.075
570	34.4	39.9	1.645	32.1	30.1	5.73	41.7	29.5	0.520	16280	5.54	56.1	7.15	66.9	8.85	84.4	10.70	102.9	12.76	114.0	0.351	0.055
575	34.2	39.9	1.828	31.4	30.9	4.19	35.3	29.6	0.520	16470	3.65	33.1	7.69	51.5	11.37	81.6	14.24	100.9	16.28	117.4	0.670	0.088
580	34.2	40.0	1.948	31.2	30.9	3.92	35.6	30.1	0.520	16750	3.37	29.7	5.94	32.3	10.99	51.7	15.35	75.4	17.91	97.4	1.201	0.123
585	33.9	40.1	1.848	30.7	31.0	7.32	38.5	30.2	0.520	16570	7.12	52.7	8.38	64.4	9.67	77.0	11.01	99.3	12.67	110.8	0.389	0.088
590	34.0	39.9	2.588	30.9	32.3	8.33	40.1	30.5	0.520	16570	8.06	66.7	9.50	77.4	10.83	94.9	12.19	112.3	14.07	125.6	0.251	0.089
595	34.0	39.9	2.671	31.2	33.1	9.75	43.2	31.4	0.520	16570	9.53	50.7	10.40	70.6	11.27	96.0	12.24	115.2	13.97	130.8	0.238	0.082
600	34.1	39.9	2.592	31.2	33.7	9.58	41.4	32.4	0.520	16670	9.36	43.2	10.44	66.4	11.46	94.9	12.48	116.0	14.95	132.8	0.256	0.091
605	34.2	39.9	2.557	31.4	34.3	10.50	39.7	33.1	0.520	16670	10.29	40.2	10.99	65.6	11.74	94.7	12.45	115.9	15.04	134.4	0.231	0.083

TABLE A2.-Concluded.

Time	PT1	SD1	FM2	PT6	SD6B	PT5B	SD5A	SD5B	FM3	VFD3C	PT10	SD10	PT11	SD11	PT12	SD12	PT13	SD13	PT14	SD14	FM4C	FM5
(sec)	(psia)	(R)	(lb/s)	(psia)	(R)	(psia)	(R)	(R)	(lb/s)	(rpm)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(lb/s)	(lb/s)
610	34.2	39.9	2.607	32.4	34.8	11.26	39.4	33.6	0.520	68	11.05	37.3	11.49	59.0	11.97	86.7	12.42	106.9	14.89	131.3	0.225	0.077
615	35.7	40.0	1.596	34.8	35.0	12.24	39.7	34.1	0.521	0	12.06	38.4	12.44	63.6	12.82	90.4	13.15	109.7	14.94	132.5	0.182	0.067
620	35.7	40.2	1.545	34.7	35.2	12.87	39.6	34.4	0.522	0	12.66	38.8	12.94	64.1	13.23	91.8	13.52	111.1	14.86	135.4	0.158	0.060
625	35.8	40.2	1.047	34.8	35.5	13.25	39.4	34.8	0.522	0	13.04	38.9	13.31	63.2	13.56	91.0	13.80	110.5	14.87	135.1	0.146	0.053
630	35.9	40.2	1.064	35.0	35.8	13.66	39.4	35.2	0.522	0	13.46	39.1	13.69	62.6	13.82	89.6	14.02	109.9	14.86	133.5	0.135	0.046
635	36.0	40.2	1.167	35.1	36.1	14.02	39.3	35.4	0.522	0	13.82	39.2	14.02	62.3	14.10	87.8	14.21	108.6	14.87	129.3	0.133	0.038
640	36.1	40.2	1.562	35.2	36.3	14.33	39.3	35.6	0.522	0	14.13	39.5	14.31	62.4	14.35	88.3	14.38	108.9	14.89	128.3	0.126	0.029

TABLE A3.-LIQUID HYDROGEN DESNIFICATION TEST NO. H4 DATA.

Time	PT1	SD1	FM2	PT6	SD6B	PT5B	SD5A	SD5B	FM3	VFD3C	PT10	SD10	PT11	SD11	PT12	SD12	PT13	SD13	PT14	SD14	FM4C	FM5
(sec)	(psia)	(R)	(lb/s)	(psia)	(R)	(psia)	(R)	(R)	(lb/s)	(rpm)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(lb/s)	(lb/s)
181	35.8	38.7	1.840	34.8	37.1	14.96	39.1	36.9	0.143	0	14.97	42.4	14.87	74.9	14.88	105.7	14.90	124.2	14.86	134.8	0.054	0.000
186	36.1	38.7	1.801	35.2	37.1	14.96	39.1	36.9	0.121	0	14.97	42.3	14.88	74.9	14.89	105.8	14.90	124.4	14.86	135.0	0.054	0.000
191	36.4	38.8	1.799	35.5	37.1	14.97	39.0	36.9	0.140	0	14.98	42.5	14.88	74.8	14.89	105.8	14.91	124.4	14.86	135.1	0.053	0.000
196	36.7	38.8	1.883	35.7	37.1	14.98	39.0	36.9	0.090	0	14.98	42.6	14.89	74.9	14.90	106.0	14.91	124.5	14.87	135.1	0.052	0.000
201	36.9	38.8	1.940	35.9	37.1	14.98	39.0	36.9	0.145	0	14.99	42.4	14.89	74.9	14.90	105.8	14.92	124.4	14.87	135.1	0.054	0.000
206	36.8	38.8	2.186	35.4	37.2	14.97	39.0	36.9	0.141	387	14.98	42.1	14.89	73.6	14.91	105.4	14.93	127.1	14.89	136.2	0.055	0.000
211	36.7	38.6	2.178	35.3	37.2	14.97	39.0	36.9	0.147	486	14.97	42.2	14.89	74.4	14.91	103.8	14.93	126.0	14.89	135.4	0.057	0.000
216	36.6	38.6	1.968	35.6	37.2	14.94	39.0	36.9	0.146	585	14.95	42.4	14.87	75.6	14.89	103.8	14.92	125.6	14.88	135.0	0.058	0.000
221	36.6	38.7	1.856	35.6	37.2	14.90	39.0	36.9	0.139	784	14.91	42.3	14.84	76.9	14.87	104.8	14.90	125.3	14.88	134.7	0.059	0.000
226	36.3	38.8	1.889	35.4	37.1	14.87	39.0	36.9	0.138	987	14.88	42.5	14.82	76.9	14.85	105.1	14.90	125.0	14.88	134.4	0.058	0.000
231	36.2	38.9	1.856	35.3	37.1	14.86	39.0	36.9	0.115	1187	14.87	42.4	14.82	77.4	14.86	105.5	14.91	124.7	14.89	134.0	0.059	0.000
236	36.0	38.9	1.867	35.1	37.1	14.83	39.0	36.9	0.126	1390	14.84	42.2	14.80	78.4	14.85	106.2	14.90	124.5	14.90	133.7	0.060	0.000
241	35.8	38.9	1.844	34.9	37.1	14.80	39.0	36.9	0.144	1563	14.81	42.2	14.78	80.0	14.84	107.1	14.90	124.7	14.90	133.4	0.060	0.000
246	35.8	38.8	1.869	34.9	37.1	14.77	39.0	36.9	0.146	1691	14.77	42.2	14.76	81.8	14.83	108.0	14.90	125.1	14.90	133.4	0.063	0.000
251	35.6	38.9	1.840	34.8	37.1	14.72	39.0	36.9	0.144	1892	14.73	42.1	14.73	83.3	14.81	108.6	14.89	125.6	14.90	133.4	0.064	0.000
256	35.9	38.9	1.806	35.0	37.1	14.69	39.0	36.9	0.144	2094	14.69	42.1	14.71	84.4	14.80	109.1	14.89	126.0	14.91	133.5	0.066	0.000
261	36.2	38.9	1.792	35.4	37.1	14.65	38.9	36.9	0.104	2295	14.66	42.1	14.69	85.5	14.79	109.9	14.89	126.6	14.92	133.4	0.067	0.000
266	36.4	38.8	1.873	35.5	37.1	14.61	38.9	36.9	0.113	2497	14.61	41.9	14.67	86.3	14.78	110.3	14.89	127.4	14.93	133.8	0.068	0.000
271	36.7	38.9	1.877	35.8	37.0	14.56	38.9	36.9	0.137	2698	14.56	41.7	14.63	87.2	14.76	111.0	14.88	128.1	14.93	134.3	0.070	0.000
276	37.0	38.9	1.909	36.1	37.0	14.50	38.9	36.9	0.150	2898	14.51	41.7	14.60	87.6	14.73	111.9	14.86	128.7	14.93	134.8	0.072	0.000
281	37.3	38.8	1.897	36.3	37.0	14.44	38.8	36.8	0.135	3101	14.45	41.6	14.56	88.1	14.71	112.8	14.85	129.2	14.93	135.6	0.073	0.000
286	37.6	38.8	1.910	36.6	37.0	14.38	38.7	36.8	0.139	3301	14.39	41.5	14.52	88.6	14.69	113.9	14.85	129.6	14.93	136.0	0.075	0.000
291	38.0	38.8	1.950	37.0	37.0	14.32	38.8	36.8	0.135	3504	14.33	41.5	14.48	89.3	14.66	114.8	14.83	130.2	14.93	136.3	0.077	0.000
296	38.2	38.8	1.858	37.3	36.9	14.26	38.7	36.8	0.130	3703	14.27	41.4	14.45	89.7	14.64	115.6	14.82	130.5	14.94	136.8	0.078	0.000
301	38.1	38.8	1.863	37.2	36.9	14.18	38.7	36.8	0.137	3907	14.20	41.3	14.41	90.2	14.62	116.0	14.82	131.1	14.94	137.4	0.079	0.000
306	37.8	38.8	1.936	36.9	36.9	14.13	38.7	36.7	0.139	4106	14.13	41.2	14.36	90.7	14.59	116.6	14.80	131.6	14.94	137.7	0.081	0.000
311	37.7	38.8	1.933	36.7	36.9	14.05	38.6	36.7	0.141	4307	14.05	41.2	14.31	91.0	14.56	117.1	14.79	131.9	14.94	137.9	0.083	0.000
316	37.5	38.8	1.940	36.5	36.8	13.97	38.6	36.6	0.140	4509	13.98	41.1	14.25	91.5	14.52	117.8	14.76	132.3	14.93	138.4	0.084	0.000
321	37.3	38.8	1.892	36.3	36.8	13.89	38.6	36.6	0.140	4710	13.89	40.9	14.20	91.7	14.49	118.2	14.75	132.8	14.93	138.7	0.086	0.000
326	37.1	38.8	1.926	36.1	36.8	13.81	38.6	36.6	0.139	4893	13.81	40.9	14.16	92.0	14.47	118.6	14.74	133.2	14.94	139.1	0.088	0.000
331	36.9	38.8	1.885	36.0	36.7	13.73	38.5	36.6	0.157	5011	13.73	40.7	14.09	92.0	14.42	118.8	14.72	133.4	14.94	139.3	0.089	0.000
336	36.8	38.8	1.956	35.9	36.7	13.62	38.5	36.5	0.082	5213	13.63	40.6	14.06	91.8	14.41	118.9	14.72	133.8	14.96	139.6	0.092	0.000
341	36.5	38.9	1.908	35.6	36.7	13.54	38.5	36.5	0.144	5414	13.55	40.7	13.99	92.1	14.36	119.2	14.70	134.1	14.95	139.7	0.093	0.000
346	36.4	38.8	1.891	35.5	36.6	13.45	38.5	36.5	0.144	5615	13.46	40.4	13.93	92.0	14.32	119.4	14.68	134.3	14.95	140.0	0.095	0.000

TABLE A3.-Continued.

Time	PT1	SD1	FM2	PT6	SD6B	PT5B	SD5A	SD5B	FM3	VFD3C	PT10	SD10	PT11	SD11	PT12	SD12	PT13	SD13	PT14	SD14	FM4C	FM5
(sec)	(psia)	(R)	(lb/s)	(psia)	(R)	(psia)	(R)	(R)	(lb/s)	(rpm)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(lb/s)	(lb/s)
351	36.3	38.8	1.885	35.3	36.6	13.35	38.4	36.4	0.144	5817	13.35	40.5	13.85	92.0	14.27	119.5	14.64	134.5	14.94	140.2	0.097	0.000
356	36.1	38.8	1.898	35.2	36.5	13.23	38.4	36.4	0.153	6019	13.24	40.3	13.78	91.5	14.22	119.7	14.62	134.7	14.94	140.4	0.099	0.000
361	36.1	38.8	1.817	35.1	36.5	13.13	38.3	36.3	0.131	6220	13.14	40.2	13.72	91.3	14.19	119.5	14.61	134.8	14.94	140.6	0.101	0.000
366	35.8	38.8	1.843	35.0	36.5	13.03	38.3	36.3	0.146	6421	13.03	40.2	13.65	91.2	14.15	119.8	14.59	135.1	14.95	140.7	0.103	0.000
371	35.6	38.8	1.811	34.7	36.4	12.92	38.2	36.2	0.137	6623	12.92	39.8	13.60	91.5	14.12	120.1	14.59	135.6	14.97	141.3	0.103	0.000
376	35.5	38.8	1.867	34.5	36.4	12.81	38.3	36.2	0.142	6824	12.80	40.1	13.53	91.3	14.08	120.3	14.57	135.6	14.97	141.5	0.105	0.000
381	35.3	38.8	1.873	34.4	36.3	12.70	38.4	36.1	0.155	7025	12.70	39.9	13.43	91.0	14.00	120.1	14.51	135.7	14.94	141.8	0.107	0.000
386	35.3	38.8	1.903	34.3	36.3	12.58	38.4	36.1	0.154	7226	12.58	39.8	13.37	90.7	13.96	120.1	14.50	135.9	14.94	141.9	0.109	0.000
391	35.1	38.8	1.886	34.3	36.2	12.45	38.3	36.0	0.140	7426	12.45	39.6	13.30	90.2	13.92	120.0	14.48	136.0	14.94	142.1	0.111	0.000
396	34.3	38.8	1.479	33.7	36.1	12.14	38.2	36.0	0.517	7629	12.13	39.3	13.35	87.0	14.18	119.1	14.79	135.4	15.19	141.9	0.124	0.000
401	34.2	38.7	1.872	33.4	36.0	11.79	38.2	35.7	0.519	7829	11.79	38.1	13.00	71.2	13.85	107.9	14.53	122.9	15.05	132.9	0.243	0.000
406	34.1	38.7	1.814	33.3	35.9	11.80	38.1	35.6	0.519	8030	11.78	36.1	12.73	75.9	13.50	108.2	14.17	126.9	14.75	135.7	0.210	0.000
411	34.1	38.7	1.829	33.2	36.0	11.96	38.3	35.6	0.519	8225	12.00	40.8	12.84	77.9	13.55	109.1	14.21	128.1	14.81	136.9	0.195	0.000
416	34.2	38.6	1.915	33.3	35.9	11.93	38.3	35.6	0.519	8333	11.93	42.5	12.83	85.7	13.52	112.8	14.14	133.1	14.71	140.2	0.161	0.000
421	34.8	38.7	1.831	33.9	36.0	12.01	39.5	35.7	0.168	8535	11.96	47.0	12.79	97.5	13.48	122.1	14.15	137.4	14.76	142.3	0.134	0.000
426	35.0	38.7	1.874	34.1	36.0	11.94	40.1	35.7	0.159	8736	11.94	46.0	12.84	98.8	13.60	125.6	14.30	139.4	14.94	143.8	0.119	0.000
431	35.2	38.7	1.900	34.2	35.9	11.68	40.8	35.6	0.116	8938	11.67	42.7	12.72	93.1	13.54	123.8	14.27	138.5	14.89	143.8	0.131	0.000
436	35.5	38.8	1.919	34.6	35.9	11.24	41.3	35.6	0.108	9137	11.31	43.7	12.86	93.9	13.90	122.4	14.73	137.7	15.39	143.8	0.161	0.000
441	35.7	38.8	1.917	34.8	35.8	11.44	44.8	35.6	0.128	9338	11.27	42.0	12.29	91.5	13.10	122.0	13.88	137.9	14.60	145.1	0.150	0.000
446	35.9	38.8	1.958	35.0	35.8	11.15	56.4	35.5	0.110	9540	11.27	41.1	12.51	87.8	13.43	119.8	14.30	137.5	15.07	145.0	0.161	0.000
451	36.1	38.8	1.952	35.0	35.7	11.19	57.7	35.5	0.128	9741	11.06	40.9	11.94	86.3	12.71	118.3	13.52	136.9	14.31	144.8	0.162	0.000
456	36.4	38.7	1.991	35.3	35.6	11.17	50.8	35.4	0.133	9741	11.18	41.2	12.42	90.2	13.35	120.6	14.22	138.2	15.01	145.5	0.162	0.000
461	36.7	38.7	1.993	35.6	35.6	11.20	40.5	35.3	0.104	9741	11.39	48.0	12.80	98.7	13.78	123.8	14.65	138.5	15.42	145.4	0.171	0.000
466	36.9	38.7	1.993	35.8	35.7	11.10	54.6	35.3	0.081	9741	11.10	41.0	12.21	88.6	13.09	120.6	13.94	138.1	14.74	146.1	0.167	0.000
471	37.2	38.8	2.031	36.1	35.6	11.05	51.5	35.3	0.130	9743	11.09	40.3	12.35	84.4	13.26	117.4	14.15	136.6	14.95	145.3	0.183	0.002
476	37.6	38.7	2.052	36.5	35.6	10.96	58.0	35.3	0.146	9741	10.92	39.6	12.35	81.1	13.37	114.0	14.26	134.5	15.09	143.9	0.201	0.000
481	37.9	38.7	2.070	36.7	35.5	10.72	49.6	35.3	0.118	9741	10.60	37.2	12.25	73.5	13.39	109.9	14.31	131.0	15.08	140.9	0.237	0.018
486	37.9	38.6	2.014	36.8	35.4	10.34	39.7	35.3	0.150	9741	10.42	34.9	12.68	60.7	14.23	96.1	15.22	118.6	15.81	130.4	0.398	0.041
491	37.8	38.6	2.113	36.5	35.3	10.02	38.0	35.0	0.128	10040	9.92	34.6	12.66	38.4	15.88	66.0	17.33	94.2	17.00	114.3	0.802	0.077
496	37.5	38.6	2.146	36.2	35.1	9.52	37.2	34.7	0.122	10540	9.28	34.4	12.11	36.1	15.53	37.1	18.61	51.5	19.30	70.1	1.638	0.099
501	37.2	38.6	2.214	35.7	34.8	8.98	36.8	34.4	0.089	10840	8.75	34.1	11.34	35.7	14.44	36.4	17.79	38.3	20.41	47.5	2.105	0.107
506	35.9	38.6	2.133	34.4	34.4	8.25	36.9	34.0	0.522	10740	8.01	33.6	10.30	35.3	13.37	35.8	16.75	38.4	18.81	53.5	1.669	0.082
511	36.4	38.6	2.204	34.8	34.0	7.56	37.1	33.5	0.524	10240	7.46	33.3	9.92	35.1	12.51	42.9	14.56	55.1	15.92	68.0	0.988	0.057
516	36.3	38.4	2.127	34.9	33.7	10.46	38.3	33.3	0.523	9741	10.46	42.2	11.48	70.2	12.41	85.4	13.38	100.9	14.33	102.6	0.323	0.048

TABLE A3.-Continued.

Time	PT1	SD1	FM2	PT6	SD6B	PT5B	SD5A	SD5B	FM3	VFD3C	PT10	SD10	PT11	SD11	PT12	SD12	PT13	SD13	PT14	SD14	FM4C	FM5
(sec)	(psia)	(R)	(lb/s)	(psia)	(R)	(psia)	(R)	(R)	(lb/s)	(rpm)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(lb/s)	(lb/s)
521	36.0	38.5	2.117	34.7	34.1	9.80	38.1	33.4	0.523	9741	9.74	40.0	11.89	68.0	13.41	91.8	14.47	107.7	15.17	114.0	0.302	0.061
526	35.8	38.5	2.042	34.6	34.4	9.38	37.4	33.5	0.523	9741	9.31	34.5	12.01	59.1	13.71	89.1	14.82	109.4	15.50	119.7	0.298	0.075
531	35.6	38.5	2.113	34.3	34.5	8.74	37.0	34.1	0.522	10040	8.62	34.0	11.21	35.7	14.27	53.6	16.32	78.2	16.64	95.8	0.854	0.085
536	35.3	38.5	2.095	34.0	34.5	8.23	37.3	33.9	0.522	10340	8.06	33.7	10.60	35.3	13.57	36.1	16.07	52.6	17.11	69.9	1.294	0.095
541	35.1	38.5	2.128	33.8	34.2	7.84	36.9	33.7	0.521	10340	7.66	33.4	9.91	35.0	12.77	35.5	15.86	47.0	17.32	65.2	1.285	0.103
546	34.9	38.5	2.245	33.5	33.8	7.49	37.1	33.4	0.520	10340	7.36	33.1	9.47	34.7	12.09	35.3	15.07	46.7	16.66	64.6	1.145	0.095
551	34.6	38.5	2.120	33.3	33.5	7.20	36.8	33.1	0.520	10140	7.13	32.9	9.18	34.6	11.99	37.9	14.55	54.1	16.06	71.5	0.884	0.096
556	34.4	38.5	2.101	33.1	33.4	7.25	37.4	33.0	0.520	10040	7.20	33.0	9.41	34.7	11.98	42.9	13.93	60.8	15.35	78.4	0.715	0.084
561	34.5	38.4	2.149	33.1	33.3	10.18	38.3	33.0	0.520	9743	10.18	40.4	11.22	62.0	12.24	79.7	13.21	99.8	14.13	105.8	0.297	0.066
566	34.6	38.4	2.125	33.3	33.9	10.15	40.0	33.0	0.520	9743	10.13	35.7	11.26	59.5	12.20	86.2	13.11	107.4	13.98	114.5	0.253	0.074
571	34.7	38.5	2.088	33.4	34.2	9.49	37.9	33.2	0.520	9741	9.39	35.3	11.68	57.8	13.28	86.0	14.44	107.4	15.16	118.5	0.328	0.092
576	34.8	38.5	2.136	33.4	34.4	8.81	37.5	33.6	0.520	10040	8.70	34.0	11.15	36.2	14.37	54.0	16.42	79.7	16.60	97.7	0.842	0.108
581	34.9	38.5	2.232	33.5	34.4	8.41	37.7	34.0	0.521	10440	8.17	33.7	10.44	35.2	13.57	35.8	16.12	44.3	18.07	64.0	1.499	0.138
586	35.3	38.5	2.227	33.9	34.2	7.90	37.2	33.8	0.179	10750	7.69	33.4	9.72	35.0	12.52	35.4	15.36	37.3	18.13	46.8	1.739	0.156
591	35.5	38.5	2.242	33.9	33.9	7.38	35.9	33.5	0.265	10560	7.21	33.1	9.18	34.6	11.77	35.0	14.68	36.9	17.21	48.2	1.468	0.149
596	35.4	38.5	2.243	33.9	33.5	7.04	36.0	33.1	0.336	10340	6.88	32.8	8.78	34.4	11.27	34.8	14.32	41.4	16.73	56.4	1.190	0.141
601	35.6	38.4	2.159	34.0	33.2	6.89	36.3	32.9	0.276	10240	6.71	32.7	8.57	34.3	11.23	34.7	14.23	41.9	16.37	57.6	1.093	0.141
606	35.7	38.4	2.321	34.0	33.1	6.82	36.2	32.8	0.523	10140	6.68	32.7	8.56	34.3	11.31	34.8	14.22	46.2	16.19	62.9	0.947	0.134
611	35.8	38.4	2.229	34.2	33.1	6.89	36.7	32.7	0.523	10140	6.79	32.7	8.81	34.4	11.37	35.2	14.34	51.1	16.04	66.4	0.858	0.131
616	36.0	38.4	2.255	34.4	33.1	6.82	36.3	32.7	0.523	10140	6.70	32.7	8.72	34.3	11.34	34.8	14.12	44.5	15.94	62.0	0.983	0.137
621	36.2	38.4	2.277	34.5	33.1	6.86	36.9	32.7	0.524	10140	6.75	32.7	8.63	34.3	11.23	34.8	14.15	45.4	16.15	63.8	0.955	0.133
626	36.4	38.4	2.270	34.9	33.1	6.86	36.0	32.7	0.524	10140	6.77	32.7	8.57	34.3	11.22	34.8	14.14	46.9	16.08	64.9	0.930	0.132
631	36.6	38.4	2.286	34.9	33.1	6.89	37.1	32.7	0.524	10140	6.73	32.7	8.67	34.4	11.28	34.9	14.27	49.0	16.13	66.4	0.894	0.134
636	36.7	38.4	2.259	35.2	33.1	6.91	36.7	32.7	0.525	10140	6.79	32.7	8.80	34.3	11.35	35.0	14.23	50.6	15.90	67.2	0.851	0.135
641	36.7	38.4	2.271	35.1	33.1	6.83	36.4	32.7	0.525	10240	6.69	32.6	8.53	34.2	11.12	34.6	14.19	39.4	16.30	56.2	1.094	0.139
646	36.5	38.5	2.256	34.9	33.1	6.73	37.0	32.7	0.524	10240	6.59	32.6	8.52	34.2	11.04	34.6	14.01	42.5	16.04	59.0	0.985	0.138
651	36.2	38.4	2.253	34.6	33.0	6.70	36.7	32.6	0.524	10140	6.57	32.6	8.48	34.2	11.02	34.6	13.94	45.7	15.86	61.7	0.904	0.135
656	36.1	38.5	2.262	34.5	33.0	6.71	36.7	32.6	0.523	10240	6.58	32.5	8.46	34.1	11.05	34.6	13.94	43.0	15.93	59.4	0.954	0.140
661	35.8	38.5	2.228	34.2	33.0	6.67	37.3	32.6	0.523	10240	6.54	32.6	8.47	34.2	10.85	34.6	13.88	42.3	15.93	58.4	0.964	0.142
666	35.6	38.5	2.259	34.1	32.9	6.69	36.2	32.5	0.522	10140	6.56	32.5	8.47	34.2	10.97	34.6	13.96	47.0	15.90	63.3	0.857	0.137
671	35.4	38.5	2.205	33.9	32.9	6.73	36.2	32.5	0.522	10140	6.63	32.6	8.43	34.2	10.93	34.7	13.93	49.1	15.81	65.0	0.819	0.133
676	35.1	38.4	2.190	33.7	32.9	6.63	35.9	32.5	0.521	10240	6.48	32.5	8.32	34.1	10.82	34.5	13.84	38.8	16.14	53.9	1.075	0.140
681	34.9	38.4	2.164	33.6	32.9	6.63	36.3	32.5	0.521	10240	6.50	32.5	8.26	34.1	10.72	34.5	13.68	41.6	16.25	56.4	1.000	0.141
686	34.8	38.5	2.114	33.4	32.9	6.57	36.4	32.5	0.520	10240	6.44	32.5	8.33	34.1	10.80	34.5	13.74	43.1	15.83	59.0	0.913	0.139

TABLE A3.-Continued.

Time	PT1	SD1	FM2	PT6	SD6B	PT5B	SD5A	SD5B	FM3	VFD3C	PT10	SD10	PT11	SD11	PT12	SD12	PT13	SD13	PT14	SD14	FM4C	FM5
(sec)	(psia)	(R)	(lb/s)	(psia)	(R)	(psia)	(R)	(R)	(lb/s)	(rpm)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(lb/s)	(lb/s)
691	34.5	38.4	2.126	33.2	32.8	6.59	36.0	32.4	0.520	10240	6.44	32.4	8.20	34.0	10.67	34.4	13.55	40.3	16.37	53.5	1.064	0.145
696	34.4	38.5	2.134	33.0	32.8	6.56	36.8	32.4	0.520	10140	6.45	32.4	8.25	34.0	10.75	34.4	13.73	43.3	15.88	58.0	0.910	0.142
701	34.4	38.5	1.868	33.4	32.8	6.56	36.2	32.4	0.519	10140	6.47	32.4	8.39	34.0	10.70	34.5	13.56	45.5	15.63	60.8	0.840	0.139
706	34.1	38.6	1.896	33.1	32.8	6.54	35.9	32.4	0.519	10140	6.42	32.4	8.21	34.0	10.77	34.6	13.75	46.2	15.86	61.8	0.816	0.138
711	33.9	38.6	1.823	32.9	32.8	6.47	36.1	32.4	0.519	10140	6.34	32.4	8.22	34.0	10.72	34.4	13.72	42.7	15.88	57.8	0.918	0.140
716	33.7	38.6	1.862	32.8	32.8	6.50	36.6	32.4	0.518	10140	6.37	32.4	8.19	34.0	10.66	34.4	13.67	44.7	15.85	60.2	0.862	0.137
721	33.6	38.6	1.914	32.8	32.7	6.48	36.4	32.4	0.518	10140	6.36	32.4	8.21	34.0	10.65	34.4	13.57	43.0	15.80	58.3	0.902	0.138
726	33.4	38.6	1.790	32.5	32.8	6.42	33.1	32.4	0.517	10240	6.27	32.3	7.94	33.9	10.48	34.3	13.43	37.6	15.85	52.1	1.016	0.143
731	33.3	38.6	1.854	32.4	32.8	6.41	36.4	32.4	0.517	10240	6.27	32.3	7.96	33.9	10.40	34.3	13.41	37.0	15.94	51.2	1.009	0.145
736	33.0	38.6	1.786	32.2	32.7	6.32	36.5	32.3	0.517	10240	6.16	32.3	7.91	33.9	10.43	34.3	13.45	39.2	15.96	52.7	0.956	0.145
741	32.9	38.6	1.756	32.0	32.7	6.38	36.7	32.3	0.516	10140	6.27	32.3	8.07	34.0	10.47	34.4	13.42	44.9	15.67	59.9	0.801	0.138
746	32.8	38.6	1.821	31.8	32.7	6.44	36.2	32.3	0.516	10140	6.35	32.4	8.09	34.0	10.55	34.4	13.57	45.5	15.77	61.0	0.799	0.137
751	32.6	38.6	1.777	31.7	32.7	6.41	36.1	32.3	0.515	10240	6.31	32.3	8.08	33.9	10.54	34.3	13.47	39.3	15.72	54.1	0.943	0.140
756	32.8	38.6	1.751	31.9	32.7	6.38	36.4	32.3	0.515	10240	6.25	32.3	7.93	33.9	10.36	34.3	13.30	41.7	16.20	55.9	0.911	0.144
761	32.4	38.6	1.847	31.5	32.6	6.37	36.2	32.3	0.514	10240	6.25	32.3	7.92	33.8	10.25	34.2	13.26	37.1	15.94	50.0	1.018	0.144
766	32.4	38.6	1.804	31.5	32.6	6.32	36.5	32.3	0.514	10240	6.20	32.3	8.01	33.9	10.33	34.2	13.25	40.3	15.94	54.3	0.905	0.143
771	32.2	38.6	1.816	31.4	32.6	6.24	34.7	32.3	0.513	10240	6.09	32.2	7.76	33.8	10.23	34.3	13.18	36.4	16.05	49.2	1.026	0.147
776	32.1	38.6	1.776	31.3	32.6	6.37	36.1	32.3	0.513	10140	6.25	32.3	8.07	33.9	10.52	34.3	13.55	45.0	15.70	59.9	0.784	0.138
781	32.0	38.6	1.794	31.2	32.7	6.35	36.7	32.3	0.513	10240	6.19	32.3	7.89	33.8	10.28	34.2	13.15	37.0	15.96	48.8	1.036	0.146
786	32.1	38.6	1.785	31.2	32.7	6.28	36.0	32.3	0.513	10240	6.13	32.3	7.91	33.8	10.26	34.2	13.30	37.3	15.87	47.4	1.040	0.149
791	32.2	38.6	1.819	31.3	32.6	6.24	36.0	32.3	0.514	10240	6.12	32.2	7.89	33.8	10.28	34.2	13.27	37.2	15.87	50.1	0.974	0.146
796	32.4	38.6	1.815	31.5	32.6	6.29	36.4	32.2	0.514	10140	6.16	32.2	7.85	33.8	10.26	34.2	13.23	39.0	15.90	52.6	0.924	0.143
801	32.6	38.6	1.797	31.6	32.6	6.24	36.3	32.2	0.514	10240	6.09	32.2	7.86	33.8	10.27	34.2	13.27	37.7	15.77	51.1	0.946	0.145
806	32.7	38.6	1.794	31.8	32.5	6.23	36.4	32.2	0.515	10240	6.10	32.2	7.81	33.8	10.20	34.1	13.11	37.6	15.99	50.0	0.972	0.146
811	32.7	38.7	1.830	31.8	32.6	6.25	36.2	32.3	0.515	10140	6.15	32.2	7.96	33.9	10.37	34.3	13.26	42.2	15.53	55.7	0.818	0.144
816	33.0	38.6	1.822	32.0	32.5	6.17	36.3	32.2	0.515	10340	5.98	32.2	7.82	33.8	10.39	34.3	13.43	42.9	15.93	56.9	0.873	0.143
821	33.1	38.6	1.830	32.2	32.6	6.13	35.6	32.2	0.516	10640	5.94	32.1	7.73	33.7	10.12	34.1	13.11	36.6	16.32	46.5	1.153	0.151
826	33.2	38.6	1.822	32.3	32.5	5.93	35.8	32.2	0.517	10950	5.76	31.9	7.42	33.5	9.77	34.0	12.92	36.2	16.25	44.5	1.170	0.156
831	33.4	38.7	1.847	32.5	32.4	5.84	35.3	32.1	0.517	11250	5.67	31.8	7.44	33.5	9.75	33.9	12.74	36.1	16.45	42.1	1.201	0.166
836	33.6	38.6	1.855	32.7	32.3	5.61	35.0	31.9	0.517	11350	5.41	31.6	6.99	33.3	9.46	33.8	12.68	36.0	16.40	44.4	1.199	0.159
841	33.7	38.6	1.852	32.6	32.1	5.42	34.5	31.7	0.518	11550	5.19	31.5	6.99	33.2	9.49	33.6	12.62	36.0	16.40	46.6	1.165	0.154
846	34.0	38.6	1.847	32.9	32.0	5.22	34.9	31.6	0.297	11650	4.95	31.3	6.71	33.0	9.23	33.6	12.75	37.5	16.17	49.8	1.082	0.154
851	34.1	38.6	1.860	33.1	31.8	5.18	34.8	31.4	0.518	11850	4.98	31.2	6.61	33.0	9.02	33.5	12.32	37.5	16.48	49.0	1.145	0.153
856	34.2	38.6	1.896	33.3	31.7	5.02	31.3	31.3	0.519	12050	4.79	31.1	6.57	32.8	9.01	33.4	12.63	36.9	16.12	48.9	1.135	0.153

TABLE A3.-Continued.

Time	PT1	SD1	FM2	PT6	SD6B	PT5B	SD5A	SD5B	FM3	VFD3C	PT10	SD10	PT11	SD11	PT12	SD12	PT13	SD13	PT14	SD14	FM4C	FM5
(sec)	(psia)	(R)	(lb/s)	(psia)	(R)	(psia)	(R)	(R)	(lb/s)	(rpm)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(lb/s)	(lb/s)
861	34.3	38.6	1.897	33.3	31.6	4.85	31.1	31.2	0.239	12250	4.65	30.9	6.36	32.7	8.73	33.3	12.42	36.6	16.21	50.7	1.116	0.153
866	34.4	38.6	1.907	33.4	31.4	4.81	31.7	31.0	0.519	12250	4.60	30.8	6.22	32.7	8.72	33.3	12.35	36.5	16.37	51.3	1.106	0.151
871	34.9	38.6	1.858	33.9	31.3	4.68	33.1	30.9	0.318	12250	4.46	30.7	6.18	32.6	8.62	33.2	12.30	37.1	16.28	51.4	1.088	0.150
876	34.7	38.6	1.961	33.7	31.3	4.59	33.2	30.9	0.409	12150	4.43	30.7	6.14	32.6	8.96	33.5	12.76	45.5	15.77	61.0	0.857	0.142
881	34.8	38.6	1.918	33.8	31.2	4.67	33.7	30.8	0.521	12240	4.53	30.7	6.17	32.6	8.77	33.3	12.58	40.6	16.09	55.7	0.990	0.144
886	34.9	38.6	1.916	33.8	31.2	4.63	33.9	30.8	0.521	12150	4.45	30.6	6.24	32.5	8.99	33.4	12.75	41.1	15.90	56.9	0.954	0.144
891	35.2	38.6	1.926	34.1	31.2	4.61	34.1	30.8	0.521	12150	4.42	30.7	6.10	32.6	8.78	33.4	12.65	42.6	15.89	58.5	0.915	0.143
896	35.6	38.6	1.976	34.5	31.2	4.57	34.6	30.8	0.200	12150	4.39	30.7	6.18	32.6	8.89	33.4	12.72	42.4	15.97	57.8	0.933	0.144
901	35.4	38.6	1.970	34.4	31.2	4.63	34.1	30.7	0.522	12150	4.48	30.7	6.13	32.7	8.99	33.5	12.92	44.8	16.00	60.7	0.880	0.142
906	35.5	38.6	1.965	34.4	31.2	4.68	34.4	30.7	0.522	12050	4.54	30.7	6.43	32.7	9.36	34.0	12.95	48.7	15.60	64.4	0.801	0.138
911	35.7	38.5	1.976	34.6	31.2	4.69	34.3	30.7	0.522	12150	4.51	30.7	6.14	32.7	9.05	33.5	12.88	44.2	16.05	60.4	0.929	0.140
916	35.9	38.6	1.955	34.8	31.2	4.71	35.1	30.8	0.523	12150	4.48	30.8	6.39	32.7	9.33	33.6	13.06	47.3	15.88	63.6	0.848	0.139
921	36.0	38.6	2.001	34.9	31.2	4.70	34.6	30.8	0.523	12150	4.53	30.7	6.23	32.6	9.10	33.5	12.88	43.2	15.91	59.2	0.944	0.142
926	36.1	38.5	2.021	34.9	31.2	4.69	35.4	30.8	0.523	12150	4.46	30.7	6.28	32.7	9.07	33.4	12.92	43.7	16.16	59.5	0.935	0.142
931	36.2	38.6	1.973	35.1	31.3	4.68	32.3	30.8	0.524	12150	4.50	30.8	6.18	32.7	8.92	33.5	12.78	42.7	16.03	58.7	0.938	0.143
936	36.5	38.6	1.992	35.3	31.3	4.66	35.1	30.8	0.524	12150	4.45	30.7	6.16	32.6	9.00	33.4	12.74	41.2	15.88	57.2	0.955	0.144
941	36.6	38.6	2.031	35.4	31.2	4.66	34.9	30.8	0.524	12150	4.48	30.7	6.30	32.6	9.11	33.5	12.77	43.7	15.80	59.1	0.909	0.142
946	36.6	38.5	1.979	35.5	31.2	4.74	34.2	30.7	0.524	12050	4.58	30.8	6.39	32.8	9.34	35.2	12.99	50.5	15.82	66.1	0.762	0.137
951	36.8	38.5	2.025	35.6	31.2	4.75	34.4	30.8	0.525	12150	4.53	30.8	6.11	32.7	8.83	33.4	12.60	42.1	16.41	58.0	1.005	0.143
956	37.1	38.5	1.996	35.9	31.3	4.65	34.6	30.9	0.456	12150	4.43	30.7	6.15	32.6	9.09	33.5	12.74	44.2	15.64	59.9	0.894	0.141
961	37.0	38.5	2.040	35.8	31.2	4.71	34.7	30.8	0.525	12250	4.44	30.7	6.06	32.6	8.79	33.2	12.50	37.4	16.31	49.7	1.139	0.149
966	37.0	38.6	2.004	35.9	31.3	4.64	34.8	30.8	0.526	12250	4.41	30.8	6.16	32.5	8.87	33.3	12.65	38.5	16.19	53.3	1.031	0.149
971	37.1	38.6	2.053	35.9	31.2	4.67	31.1	30.8	0.525	12160	4.49	30.7	6.29	32.6	9.09	33.5	12.81	44.4	15.80	59.9	0.899	0.142
976	36.9	38.5	2.034	35.7	31.2	4.63	30.5	30.7	0.525	12450	4.39	30.6	5.99	32.5	8.64	33.2	12.37	37.9	16.32	53.1	1.079	0.147
981	36.6	38.6	1.981	35.5	31.2	4.52	30.5	30.8	0.524	12660	4.29	30.6	5.96	32.4	8.83	33.3	12.73	41.1	16.02	57.3	0.995	0.145
986	36.5	38.6	2.028	35.4	31.1	4.38	34.5	30.7	0.524	12850	4.11	30.4	5.74	32.3	8.66	33.2	12.63	41.3	16.18	57.4	1.002	0.146
991	36.7	38.6	2.108	35.4	31.0	4.24	33.8	30.6	0.352	12960	3.92	30.3	5.58	32.2	8.69	33.2	12.54	44.1	15.95	60.2	0.969	0.143
996	36.5	38.5	1.927	35.3	30.8	4.17	32.7	30.4	0.169	13260	3.93	30.2	5.48	32.1	8.03	32.9	11.94	37.7	16.62	51.8	1.192	0.149
1001	35.9	38.6	1.994	34.8	30.8	4.10	32.6	30.4	0.523	13360	3.87	30.1	5.47	31.9	8.13	32.9	12.32	43.2	16.26	59.2	1.027	0.144
1006	35.8	38.6	1.996	34.6	30.7	4.03	32.3	30.3	0.522	13560	3.76	29.9	5.44	31.9	8.35	33.1	12.55	45.5	16.12	62.3	0.965	0.142
1011	35.7	38.5	2.025	34.3	30.5	3.85	32.7	30.1	0.522	13710	3.60	29.8	5.06	31.7	7.82	32.7	11.97	42.2	16.54	58.7	1.083	0.145
1016	35.7	38.6	1.991	34.5	30.5	3.86	33.0	30.0	0.522	13860	3.54	29.8	5.17	31.7	7.91	32.8	12.24	45.3	16.19	62.7	0.985	0.141
1021	35.8	38.6	1.996	34.7	30.4	3.79	33.4	29.9	0.523	13960	3.50	29.7	5.06	31.6	7.92	32.8	12.35	45.9	16.28	63.2	0.989	0.142
1026	35.9	38.5	2.045	34.7	30.3	3.72	33.6	29.9	0.523	14060	3.43	29.6	4.93	31.5	7.98	32.8	12.30	45.5	16.19	63.2	1.008	0.140

TABLE A3.-Continued.

Time	PT1	SD1	FM2	PT6	SD6B	PT5B	SD5A	SD5B	FM3	VFD3C	PT10	SD10	PT11	SD11	PT12	SD12	PT13	SD13	PT14	SD14	FM4C	FM5
(sec)	(psia)	(R)	(lb/s)	(psia)	(R)	(psia)	(R)	(R)	(lb/s)	(rpm)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(lb/s)	(lb/s)
1031	36.1	38.6	2.042	34.9	30.2	3.66	33.6	29.8	0.523	14060	3.33	29.5	4.88	31.5	8.16	32.8	12.28	45.4	16.07	63.0	0.999	0.141
1036	36.2	38.5	2.012	34.9	30.2	3.65	32.7	29.8	0.523	14060	3.42	29.5	4.89	31.5	7.89	32.7	12.29	45.0	16.30	64.3	1.005	0.140
1041	36.3	38.6	2.036	35.1	30.2	3.63	32.5	29.7	0.524	14060	3.37	29.5	4.91	31.5	8.17	32.8	12.18	45.0	15.98	62.9	0.987	0.140
1046	36.4	38.5	2.042	35.2	30.1	3.65	33.0	29.6	0.524	13960	3.41	29.5	5.13	31.6	8.27	35.2	12.46	52.7	16.02	69.9	0.843	0.135
1051	36.6	38.5	2.048	35.4	30.2	3.63	33.5	29.6	0.524	14060	3.32	29.5	5.00	31.6	8.38	33.1	12.24	48.5	15.87	66.4	0.941	0.136
1056	36.6	38.5	2.052	35.5	30.1	3.65	29.5	29.6	0.524	14060	3.39	29.5	4.98	31.5	8.25	32.9	12.34	49.1	15.93	66.6	0.918	0.137
1061	36.8	38.5	2.080	35.6	30.1	3.65	29.5	29.7	0.525	14060	3.41	29.5	4.97	31.5	8.18	32.9	12.51	48.5	16.15	66.3	0.944	0.138
1066	36.9	38.5	2.052	35.7	30.1	3.68	29.4	29.6	0.525	13960	3.44	29.5	5.06	31.6	8.16	34.7	12.36	52.6	15.95	70.4	0.846	0.135
1071	37.0	38.6	2.100	35.9	30.2	3.64	29.5	29.7	0.525	14060	3.43	29.5	4.89	31.5	7.86	32.7	12.15	43.4	16.04	62.3	0.997	0.141
1076	37.0	38.5	2.055	35.8	30.1	3.65	29.4	29.6	0.525	13960	3.36	29.5	5.13	31.7	8.27	39.1	12.43	55.1	15.86	72.0	0.783	0.134
1081	36.9	38.6	2.086	35.7	30.2	3.62	29.4	29.6	0.525	14060	3.39	29.5	5.00	31.5	8.29	33.9	12.40	49.6	15.88	67.2	0.916	0.136
1086	37.0	38.5	2.080	35.9	30.1	3.55	29.4	29.6	0.172	13960	3.41	29.5	5.22	31.8	8.71	40.7	12.46	57.0	15.66	75.3	0.746	0.131
1091	36.6	38.6	2.071	35.4	30.1	3.64	32.3	29.6	0.524	13960	3.41	29.5	5.18	31.7	8.56	35.8	12.48	53.7	15.74	71.0	0.862	0.133
1096	36.4	38.5	2.021	35.2	30.1	3.62	32.9	29.6	0.524	14060	3.39	29.5	4.91	31.5	8.00	32.8	12.45	47.9	16.25	66.1	0.957	0.138
1101	36.2	38.5	2.081	35.0	30.1	3.64	29.6	29.6	0.523	13960	3.34	29.5	5.02	31.6	8.43	33.3	12.37	50.5	15.96	68.3	0.904	0.135
1106	36.0	38.5	2.028	34.9	30.1	3.63	33.2	29.6	0.523	13960	3.39	29.5	5.06	31.6	8.33	34.9	12.43	52.4	15.95	70.2	0.854	0.135
1111	35.8	38.5	2.029	34.7	30.1	3.67	32.5	29.6	0.523	13960	3.46	29.5	5.10	31.7	8.13	35.3	12.47	53.5	16.11	71.5	0.841	0.134
1116	35.7	38.5	2.014	34.5	30.1	3.66	29.6	29.6	0.522	14060	3.42	29.5	4.96	31.6	7.85	32.8	12.29	47.3	16.38	65.8	0.976	0.139
1121	35.5	38.5	1.994	34.5	30.1	3.63	32.7	29.6	0.522	13960	3.42	29.5	5.21	31.6	8.42	34.8	12.60	53.4	16.08	71.2	0.842	0.135
1126	35.4	38.5	2.038	34.2	30.1	3.62	31.0	29.6	0.522	14060	3.37	29.5	5.20	31.6	8.64	33.9	12.42	51.9	15.77	69.6	0.873	0.134
1131	35.4	38.5	1.925	34.3	30.1	3.65	29.4	29.6	0.522	14060	3.40	29.5	4.96	31.5	8.06	32.8	12.25	47.0	16.02	65.3	0.968	0.138
1136	35.4	38.5	1.963	34.4	30.1	3.63	29.4	29.6	0.522	14060	3.38	29.5	5.03	31.7	8.20	35.0	12.62	51.7	16.27	69.6	0.880	0.137
1141	35.6	38.5	2.000	34.4	30.1	3.68	29.4	29.6	0.522	14060	3.48	29.5	5.12	31.6	8.08	34.5	12.45	52.1	16.06	70.2	0.854	0.135
1146	35.8	38.6	2.064	34.5	30.2	3.63	29.5	29.7	0.522	14030	3.41	29.5	5.13	31.7	8.33	37.3	12.41	51.9	15.87	67.5	0.871	0.137
1151	35.9	38.6	1.946	34.7	30.1	3.61	29.5	29.6	0.523	14060	3.40	29.5	5.03	31.6	8.36	37.0	12.32	52.2	15.80	69.9	0.847	0.135
1156	36.0	38.5	2.020	34.8	30.1	3.57	29.4	29.6	0.523	14010	3.27	29.5	4.86	31.6	8.07	33.0	12.37	49.5	16.21	67.5	0.934	0.137
1161	36.3	38.5	2.049	35.2	30.1	3.56	29.3	29.6	0.229	14060	3.35	29.4	4.94	31.5	7.94	33.1	12.37	50.2	16.08	68.2	0.894	0.136
1166	36.2	38.6	2.025	35.0	30.1	3.55	29.3	29.6	0.524	14140	3.25	29.4	4.83	31.5	8.18	33.0	12.29	49.9	15.87	68.0	0.891	0.136
1171	36.3	38.6	1.992	35.2	30.1	3.51	29.4	29.6	0.524	14260	3.31	29.3	4.98	31.5	8.41	35.5	12.27	51.0	15.69	68.6	0.900	0.134
1176	36.5	38.5	2.052	35.3	30.0	3.53	29.3	29.5	0.524	14460	3.32	29.3	5.04	31.4	7.97	33.0	12.28	51.2	16.10	69.4	0.926	0.135
1181	36.5	38.5	2.005	35.2	30.0	3.45	29.2	29.5	0.524	14660	3.15	29.2	4.64	31.2	7.89	32.6	12.15	47.0	16.09	65.8	0.998	0.138
1186	36.6	38.5	2.002	35.4	30.0	3.36	29.1	29.5	0.525	14760	3.06	29.1	4.61	31.1	8.04	33.7	12.23	51.2	16.02	69.6	0.918	0.136
1191	36.8	38.5	2.076	35.6	29.9	3.35	29.0	29.4	0.524	14970	3.03	29.1	4.54	31.1	7.78	32.7	12.22	49.5	16.28	68.0	0.995	0.137
1196	36.8	38.5	2.086	35.6	29.8	3.32	29.0	29.3	0.525	15120	3.01	29.0	4.44	31.0	7.61	32.5	12.17	48.5	16.35	67.5	0.995	0.138

TABLE A3.-Concluded.

Time	PT1	SD1	FM2	PT6	SD6B	PT5B	SD5A	SD5B	FM3	VFD3C	PT10	SD10	PT11	SD11	PT12	SD12	PT13	SD13	PT14	SD14	FM4C	FM5
(sec)	(psia)	(R)	(lb/s)	(psia)	(R)	(psia)	(R)	(R)	(lb/s)	(rpm)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(psia)	(R)	(lb/s)	(lb/s)
1201	36.8	38.5	2.068	35.6	29.8	3.30	29.0	29.3	0.525	15270	3.04	29.0	4.47	31.1	7.41	34.0	12.22	49.9	16.67	68.6	1.004	0.139
1206	36.7	38.5	2.078	35.5	29.7	3.22	28.8	29.2	0.524	15370	2.87	28.8	4.33	30.8	7.48	33.0	12.09	50.4	16.30	69.3	1.000	0.136
1211	36.5	38.6	2.123	35.4	29.7	3.17	28.9	29.1	0.524	15570	2.82	28.8	4.32	31.0	7.85	40.4	12.25	56.4	16.05	76.1	0.859	0.133
1216	36.4	38.5	2.071	35.2	29.6	3.12	28.7	29.0	0.524	15670	2.70	28.7	4.19	30.8	7.72	34.0	11.86	52.5	16.07	71.5	0.967	0.134
1221	36.1	38.5	2.030	34.9	29.5	3.13	28.9	29.0	0.523	15770	2.77	28.7	4.18	30.6	7.33	33.2	12.04	51.4	16.37	71.0	0.987	0.136
1226	36.0	38.5	2.028	34.8	29.5	3.10	28.7	29.0	0.523	15770	2.84	28.7	4.09	30.6	7.31	33.9	11.91	51.9	16.25	71.5	0.961	0.136
1231	35.8	38.6	2.089	34.5	29.5	3.03	28.7	29.0	0.522	15770	2.67	28.6	4.10	30.6	7.71	36.5	11.99	54.6	16.07	74.1	0.901	0.134
1236	35.6	38.5	2.083	34.4	29.4	3.06	28.6	28.9	0.522	15770	2.83	28.6	4.34	30.7	7.42	34.7	12.15	56.1	16.36	75.3	0.927	0.133
1241	35.5	38.5	2.000	34.3	29.4	3.04	28.6	28.9	0.522	15770	2.75	28.6	4.23	30.6	7.53	33.0	12.10	54.8	16.19	73.8	0.944	0.133
1246	35.4	38.5	1.997	34.3	29.4	3.04	28.7	28.9	0.522	15770	2.75	28.6	4.28	30.7	7.88	35.7	12.02	56.5	15.82	75.6	0.901	0.131
1251	35.4	38.6	2.040	34.2	29.4	3.03	28.7	28.9	0.521	15770	2.77	28.6	4.31	30.7	7.72	36.0	11.98	55.6	15.87	75.1	0.896	0.131
1256	35.9	38.5	2.099	34.9	29.4	2.99	28.6	28.8	0.292	15770	2.64	28.6	4.07	30.6	7.68	33.6	11.85	53.4	15.85	72.8	0.945	0.132
1261	35.7	38.5	2.051	34.5	29.3	2.92	28.4	28.8	0.187	15770	2.55	28.4	4.13	30.6	7.74	36.7	12.10	57.7	15.98	76.4	0.888	0.130
1266	35.4	38.5	2.061	34.2	29.3	3.01	28.5	28.8	0.522	15770	2.79	28.5	4.39	30.8	7.69	40.9	12.44	60.5	16.40	80.0	0.845	0.130
1271	35.5	38.5	2.054	34.3	29.3	3.02	28.6	28.8	0.522	15770	2.76	28.6	4.23	30.7	7.29	32.9	12.19	56.0	16.61	74.4	0.965	0.134
1276	35.5	38.5	2.008	34.3	29.3	3.02	28.6	28.8	0.523	15770	2.70	28.5	4.14	30.6	7.83	37.7	12.05	57.0	15.97	76.6	0.867	0.131
1281	35.7	38.6	2.086	34.4	29.5	3.20	30.3	28.9	0.523	15670	3.05	29.0	5.92	32.1	10.35	43.4	11.37	55.3	15.18	77.7	0.728	0.127
1286	35.8	38.6	2.050	34.5	29.8	5.65	41.7	29.0	0.523	15570	5.53	61.1	8.37	67.5	10.89	76.9	10.04	89.6	12.31	100.4	0.213	0.090
1291	35.9	38.5	1.962	34.7	30.8	6.97	42.5	29.6	0.524	15570	6.91	64.0	9.12	74.8	11.53	89.9	10.89	101.5	13.07	114.0	0.165	0.095
1296	36.1	38.5	2.073	35.1	31.5	7.65	43.6	30.7	0.524	15570	7.64	62.9	9.79	78.4	11.93	97.5	12.11	108.5	14.46	118.5	0.188	0.100
1301	36.2	38.5	2.046	35.2	32.2	7.70	40.5	31.4	0.524	15570	7.65	54.8	9.83	74.0	11.81	98.3	11.83	109.9	13.70	125.3	0.243	0.092
1306	36.3	38.5	1.889	35.3	32.8	8.04	40.2	32.0	0.524	15570	8.02	44.8	10.19	68.3	12.17	96.8	12.14	109.9	13.91	127.8	0.337	0.093
1311	36.5	38.5	2.036	35.5	33.1	6.75	42.7	32.3	0.525	4157	6.61	32.8	12.09	53.1	18.00	86.3	14.71	101.6	16.50	120.7	0.620	0.111
1316	36.9	38.5	1.702	36.3	33.3	9.39	38.8	32.8	0.525	0	9.38	42.3	10.81	56.1	12.38	75.1	12.34	92.3	13.90	112.5	0.446	0.086
1321	37.0	38.6	1.758	36.3	33.4	10.06	39.2	32.7	0.525	0	10.18	43.7	11.94	69.0	13.55	92.9	13.36	105.5	14.92	120.4	0.251	0.092
1326	37.1	38.6	1.687	36.4	33.8	11.68	40.6	33.0	0.526	0	11.66	42.5	12.47	75.1	13.52	100.9	13.35	108.5	14.47	126.9	0.151	0.071
1331	36.9	38.7	1.654	36.3	34.3	12.87	40.2	33.5	0.525	0	12.04	42.8	12.50	82.3	13.23	106.3	13.27	112.5	14.08	130.1	0.113	0.048
1336	36.9	38.6	1.666	36.3	34.6	14.12	42.9	34.0	0.525	0	12.27	62.3	12.62	98.8	13.25	111.7	13.28	119.2	13.99	134.0	0.085	0.000
1341	36.8	38.6	1.622	36.1	35.1	13.41	41.8	34.5	0.525	0	13.02	59.1	13.44	99.0	14.20	117.2	14.20	121.5	14.93	133.7	0.078	0.056
1346	36.8	38.7	1.608	36.2	35.4	13.81	41.5	34.8	0.525	0	13.39	57.4	13.72	97.2	14.30	120.3	14.31	123.2	14.95	136.0	0.064	0.046
1351	36.5	38.7	1.607	36.0	35.6	14.07	41.3	35.1	0.524	0	13.67	56.8	13.92	96.4	14.42	121.0	14.43	124.2	14.98	136.3	0.057	0.040

References

1. Hannum, N.P., Technology Issues Associated with Fueling the National Aerospace Plane with Slush Hydrogen, NASA TM-101386, 1989.
2. DeWitt, R.L., Hardy, T.L., Whalen, M.V., Richter, G.P., and Tomsik, T.M., Background, Current Status and Prognosis of the Ongoing Slush Hydrogen Technology Program for the NASP, NASA TM-103220, 1990.
3. Hardy, T.L., and Whalen, M.V., Slush Hydrogen Propellant Production, Transfer, and Expulsion Studies at the NASA K-Site Facility, AIAA Paper 91-3550, Presented at the 27th JPC, Cleveland, OH, Sept. 1991.
4. Fazah, M.M., STS Propellant Densification Feasibility Study Data Book, NASA TM-108467, September 1994.
5. Lynn, E., and Graham, B., Effect of Propellant Densification on Winged-Body RLV Weight, NASA MSFC, Oct. 10, 1995.
6. Lak, T., Lozano, M. , and Tomsik, T. M., Advancement in Cryogenic Propulsion System Performance Through Propellant Densification, AIAA Paper 96-3123, Presented at the 32nd JPC, Lake Buena Vista, FL, July 1996.

TABLE I.—LH_2 PROPELLANT DENSIFICATION GSE DESIGN BASIS

LH_2 IPTD tank		LH_2 Recirc pumps	
Tank diameter, ft	10	Recirc mass flowrate, lb/sec	1.8 - 2.0
Total volume, ft^3	2706	Recirc volume flowrate, gpm	180 - 200
Ullage volume, percent	2.0	Maximum diff pressure, psid	5.0
Maximum tank pressure, psia	35.0	Head rise, ft	160 - 170
Initial propellant mass, lb	11720		
Densification time, hr	2.0		
gH_2 Compressor		**LH_2 Heat exchanger**	
Type	Centrifugal	Inlet mass flowrate, lb/sec	2.0
Driver	AC Motor	Max inlet temperature, R	42.6
Number of stages	4	Inlet pressure, psia	40.0
Design flowrate, lb/sec	0.40	Outlet temperature, R	27.0
Design inlet temperature, R	26.0	Maximum pressure drop, psid	1.0
Design inlet pressure, psia	1.2	Heat transfer rate, Btu/sec	34 - 63
Discharge pressure, psia	15.6	Bath pressure, psia	1.4 ±0.2
Horse power, GHP	40.0	Bath temperature, R	25.9 ±0.5
Design pt. speed, rpm	22000		

TABLE II.—PROPELLANT DENSIFICATION TEST DATA SUMMARY

Test number	Description	Recirc flow, lb/sec	Inlet temperature, °R	Bath pressure, psia	Outlet temperature, °R	Compressor speed, rpm	Run time, sec
N1	LN_2 Densification	1.8	144	3.0	120	8020	1070
N2	LN_2 Densification	1.5	149	3.6	121	8530	630
N3	LN_2 Densification	9.0	148	3.8	123	8020	1420
H1	LH_2 Densification	2.0	40	3.4	30	16670	470
H2	LH_2 Densification	1.9	40	7.1	34	13350	380
H3	LH_2 Densification	2.3	40	4.8	32	14760	210
H4	LH_2 Densification	2.0	39	3.0	29	15570	1110

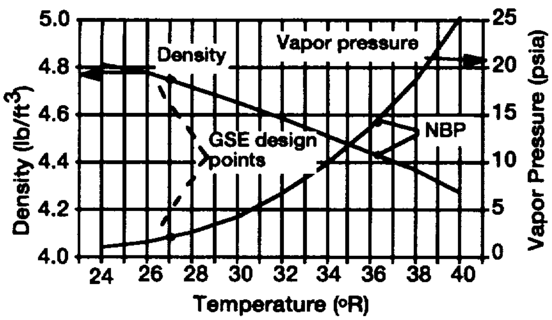


Figure 1.—Liquid hydrogen density and vapor pressure curves.

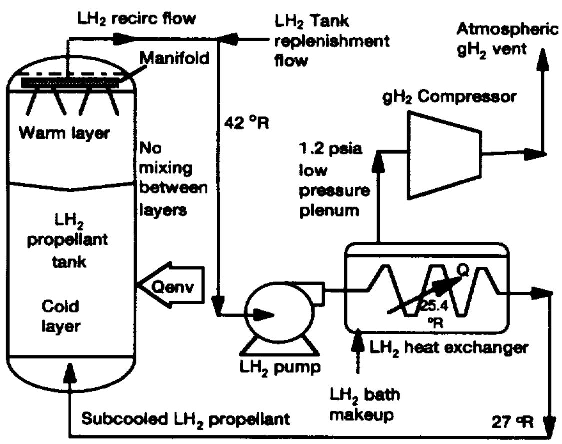


Figure 2.—Integrated RLV propellant tank and LH$_2$ propellant densification unit based on thermodynamic vent principle.

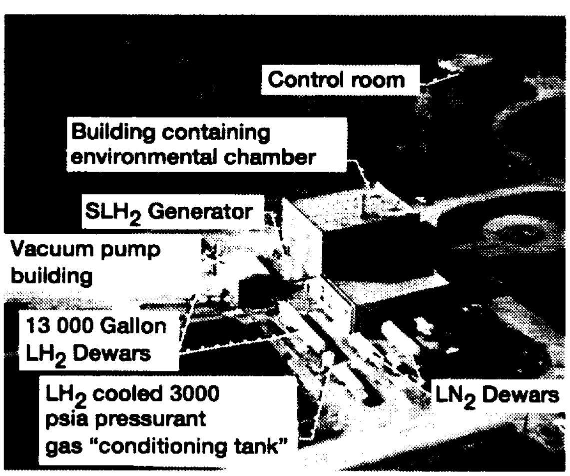


Figure 3.—NASA Plum Brook K-Site facility.

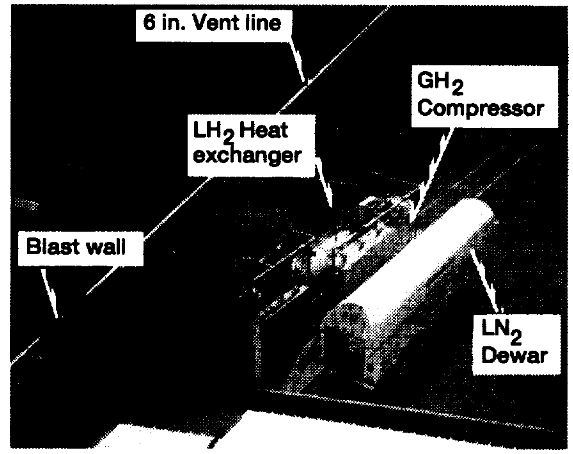


Figure 4.—LH$_2$ propellant densification GSE at K-site.

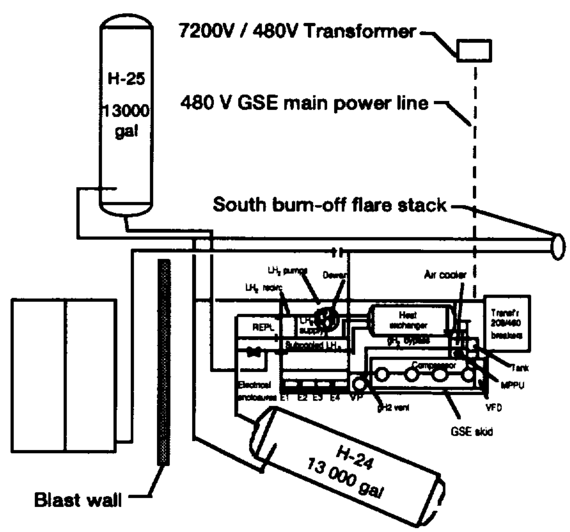


Figure 5.—LH$_2$ propellant densification GSE configuration for testing at K-Site.

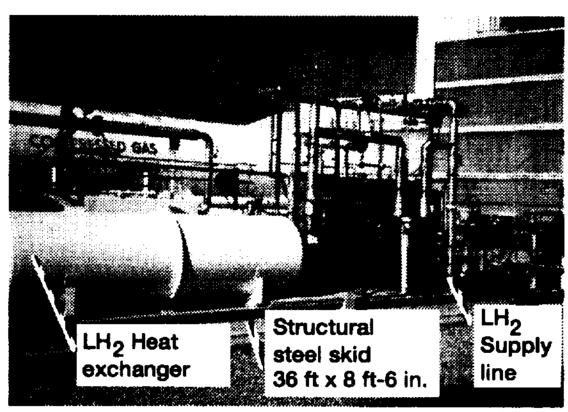


Figure 6.—Skid mounted LH$_2$ propellant densification assembly.

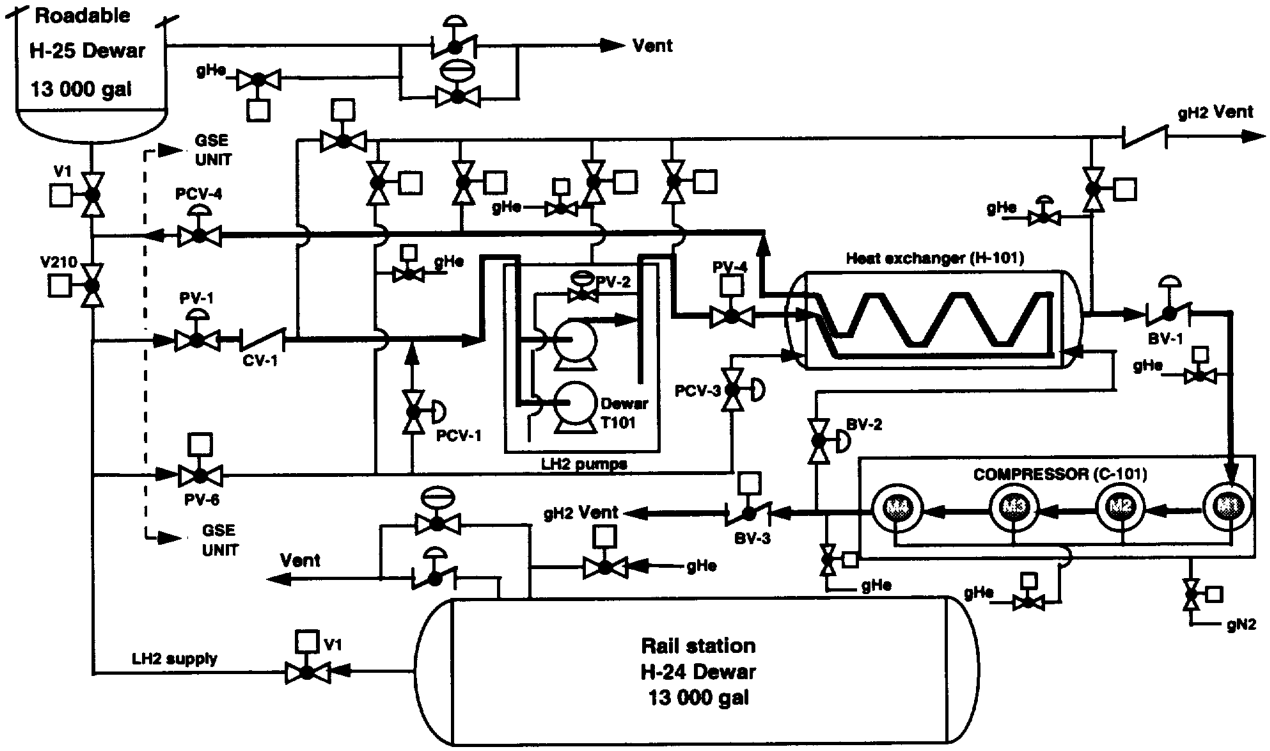


Figure 7.—LH_2 propellant densification GSE system flow schematic.

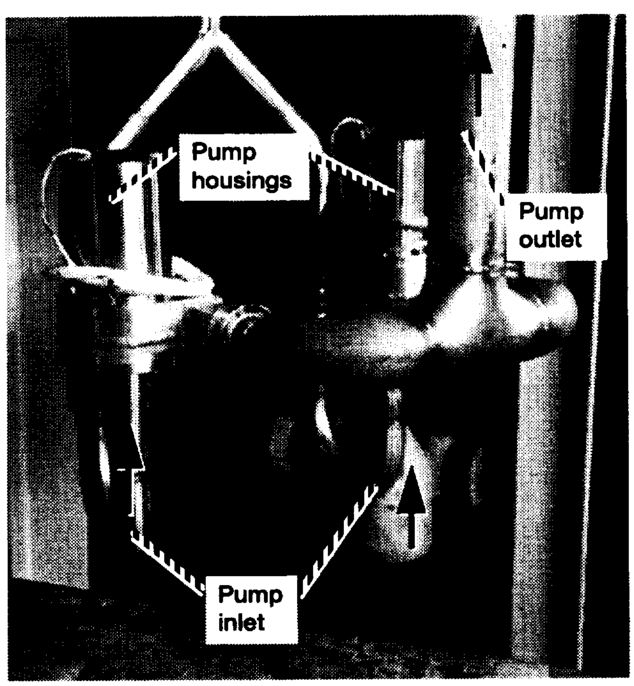


Figure 8.—LH_2 recirculation pump assembly.

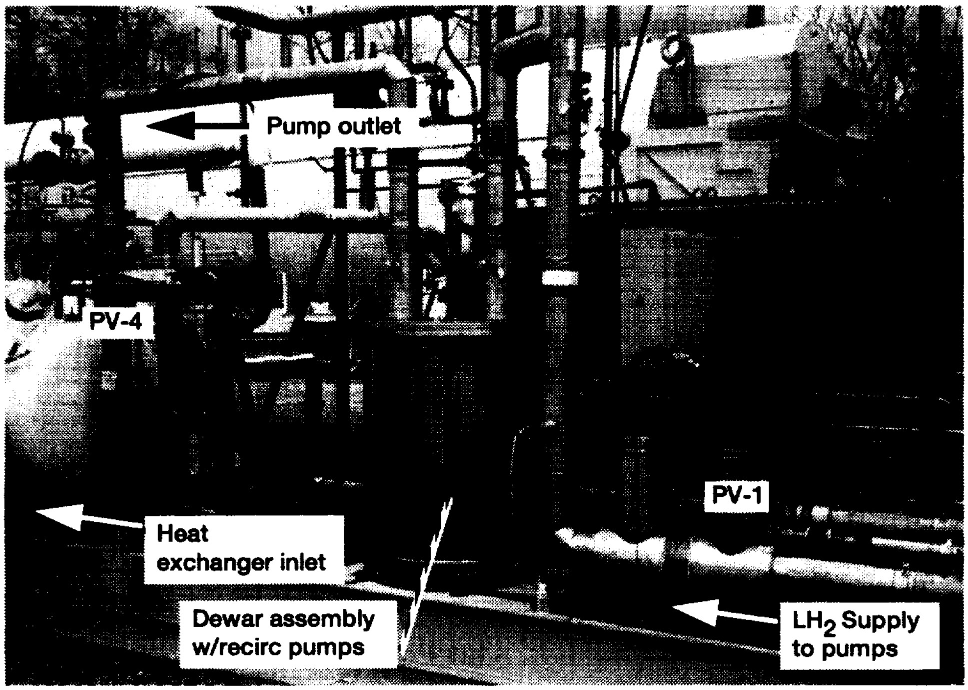
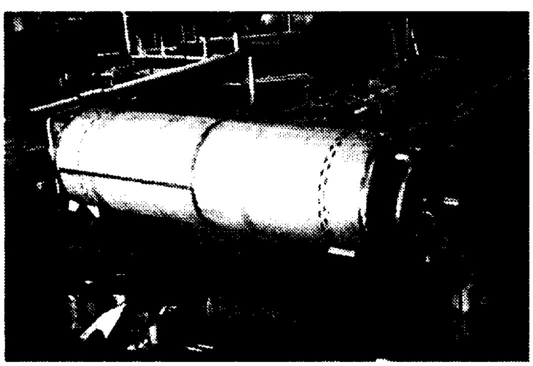
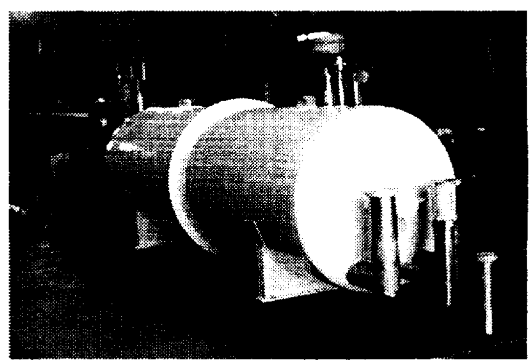


Figure 9.—LH_2 recirculation pumps mounted inside dewar.

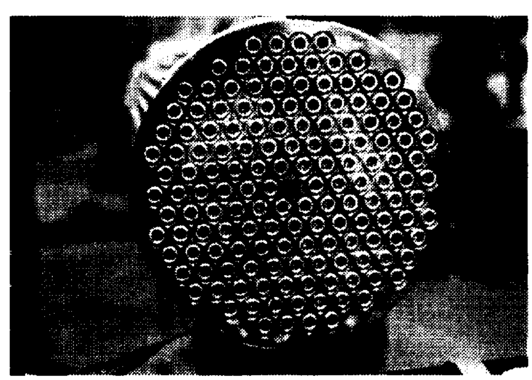


Inner shell assembly



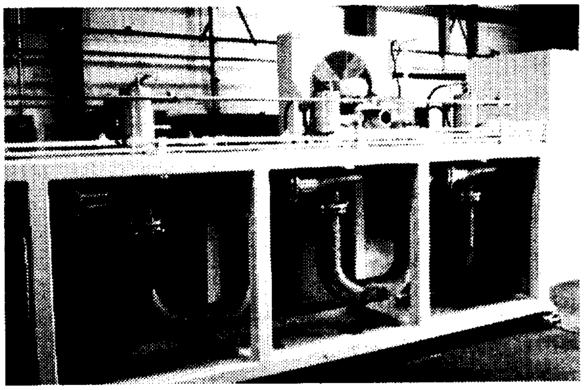
Outer shell final assembly

Tube bundle assembly

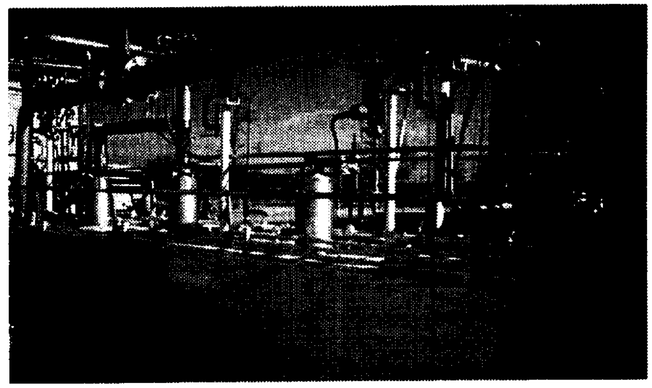


End view of tubes

Figure 10.—LH_2 heat exchanger fabrication and assembly.

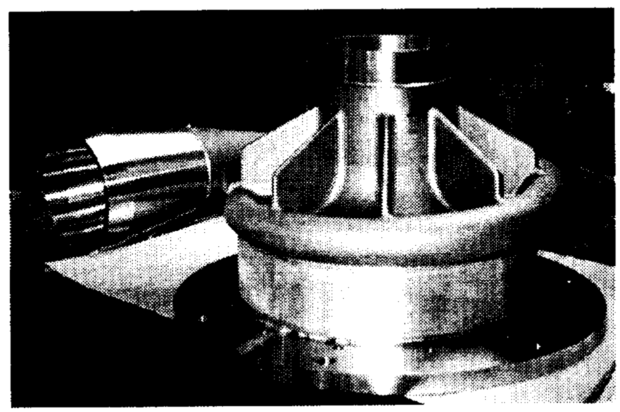


Interstage assemblies



Four stage GH_2 compressor assembly

14-in. Compressor impeller



Compressor housing

Figure 11.—Gaseous hydrogen compressor assembly.

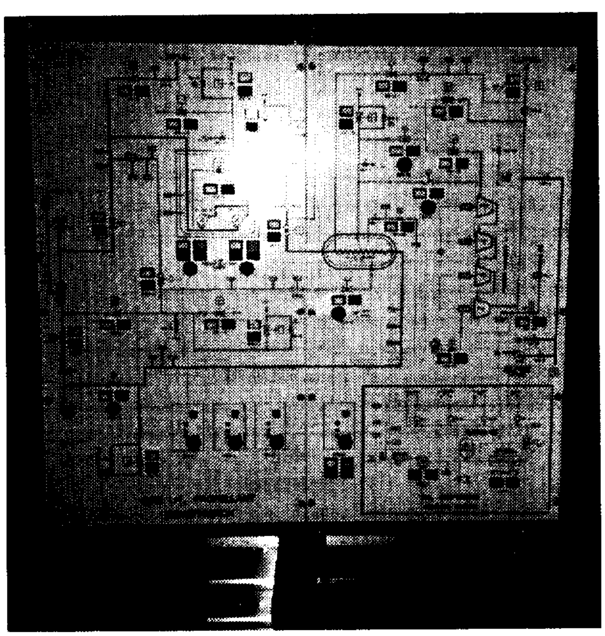


Figure 12.—LH_2 propellant densification operator control panel.

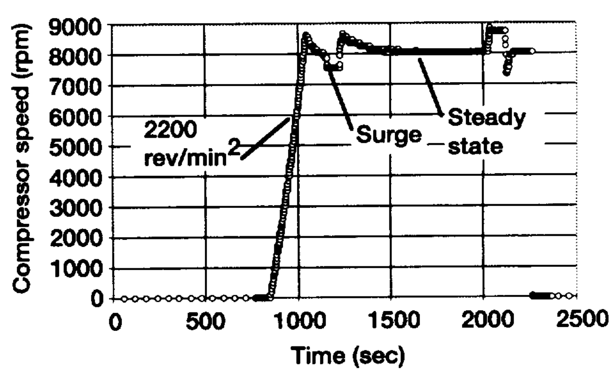


Figure 13.—Compressor speed during LN_2 densification Test N3.

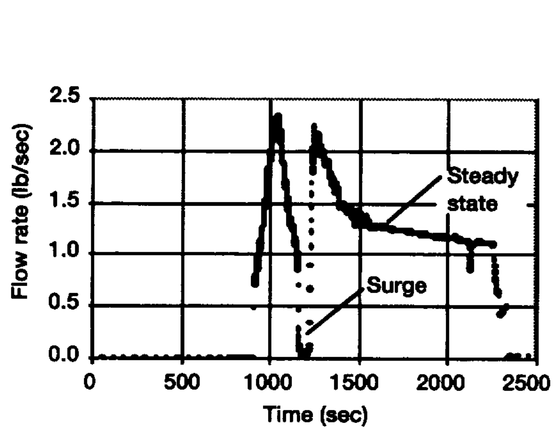


Figure 14.—Compressor discharge gN_2 mass flow rate during nitrogen densification Test N3.

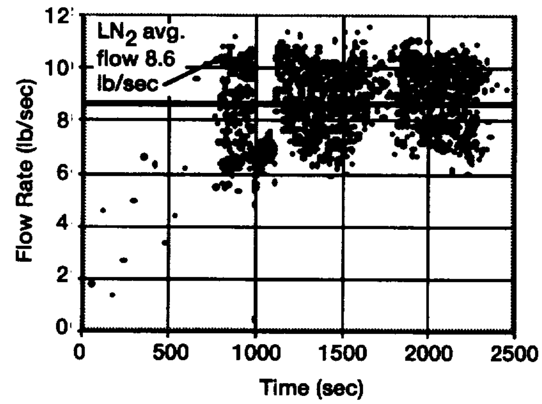


Figure 17.—Liquid nitrogen mass flow rate through GSE heat exchanger tubes during LN_2 densification Test N3.

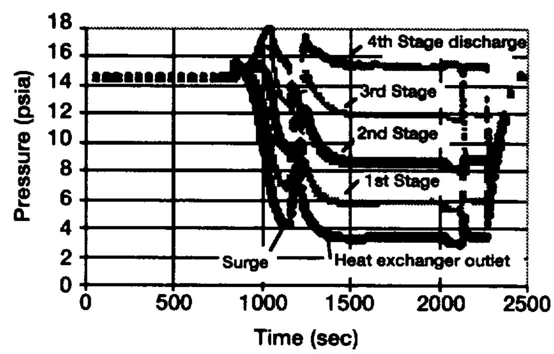


Figure 15.—Compressor stage discharge gN_2 pressures during nitrogen densification Test N3.

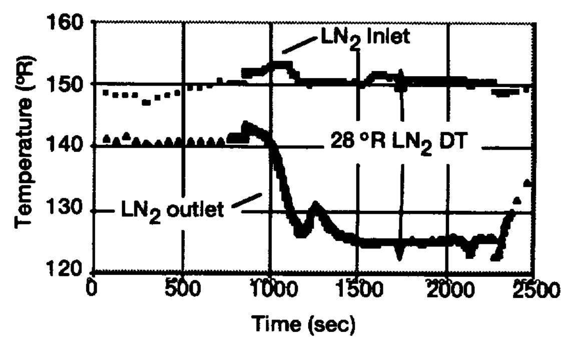


Figure 18.—Heat exchanger LN_2 inlet and outlet temperatures during nitrogen densification Test N3.

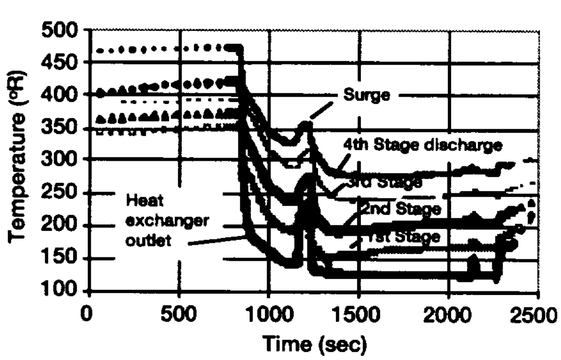


Figure 16.—Compressor stage discharge gN_2 temperatures during nitrogen densification Test N3.

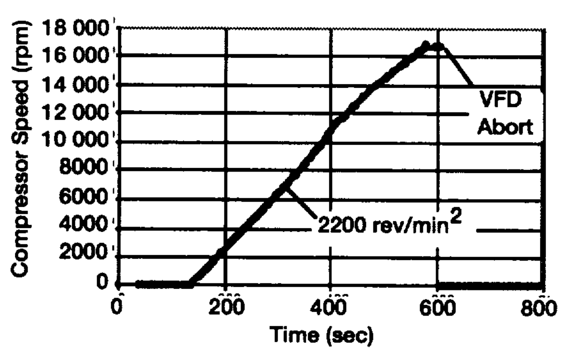


Figure 19.—Compressor speed during LH_2 densification Test H1.

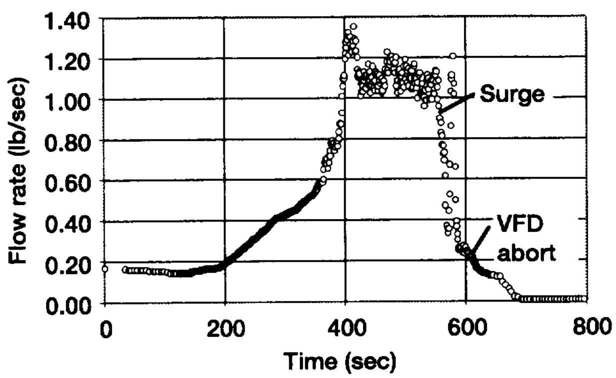


Figure 20.—Compressor discharge gH_2 mass flow rate during hydrogen densification Test H1.

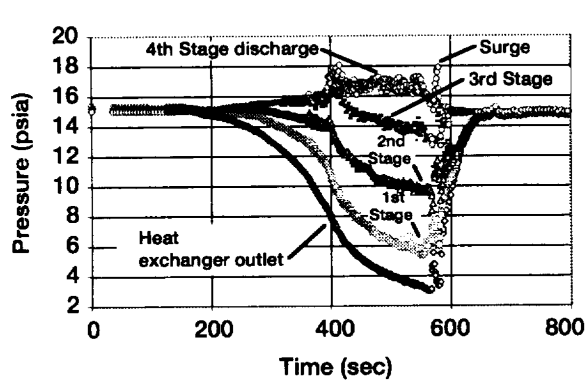


Figure 21.—Compressor stage discharge gH_2 pressures during hydrogen densification Test H1.

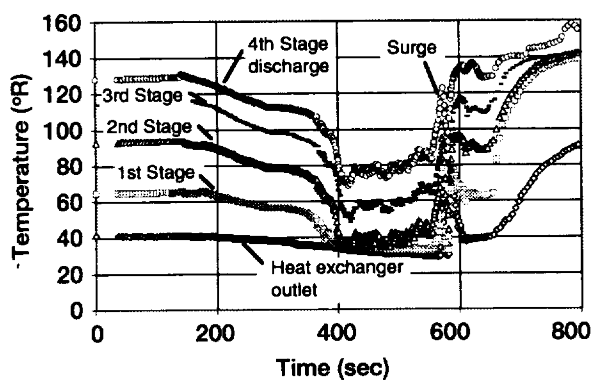


Figure 22.—Compressor stage discharge gH_2 temperatures during hydrogen densification Test H1.

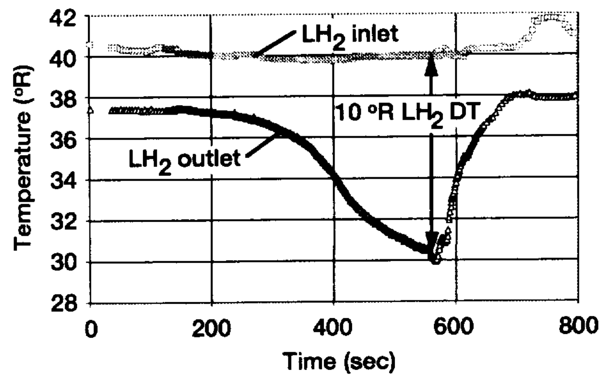


Figure 23.—Heat exchanger LH_2 inlet and outlet temperatures during hydrogen densification Test H1.

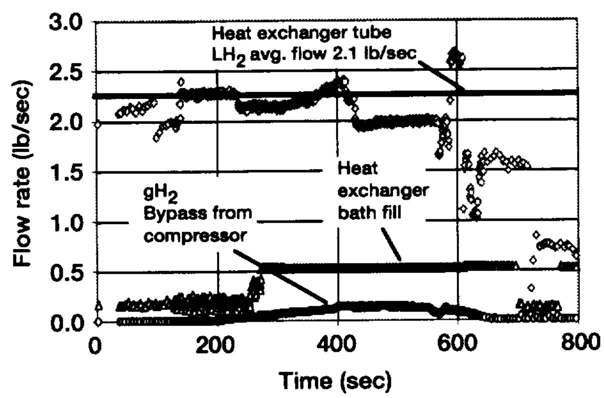


Figure 24.—Hydrogen mass flow rates entering GSE heat exchanger during LH_2 densification Test H1.

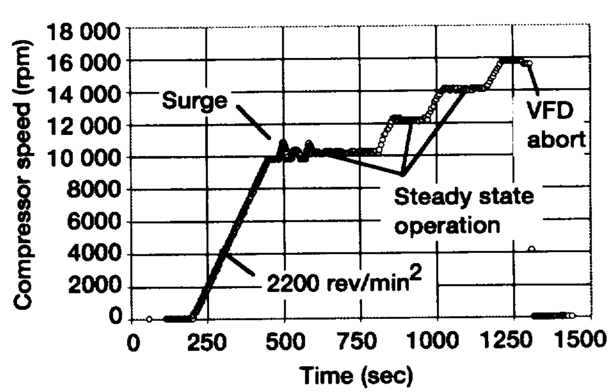


Figure 25.—Compressor speed during LH_2 densification Test H4.

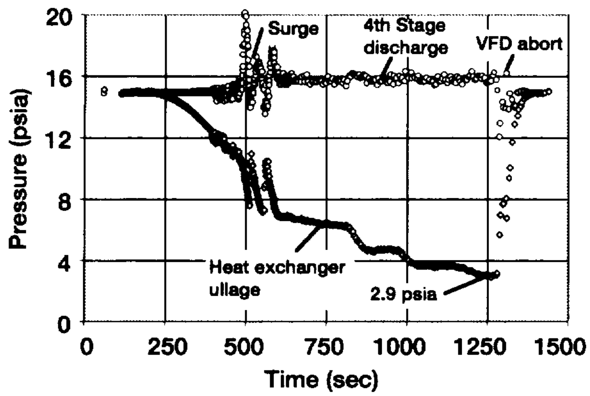


Figure 26.—Compressor discharge and heat exchanger ullage pressure during LH_2 densification Test H4.

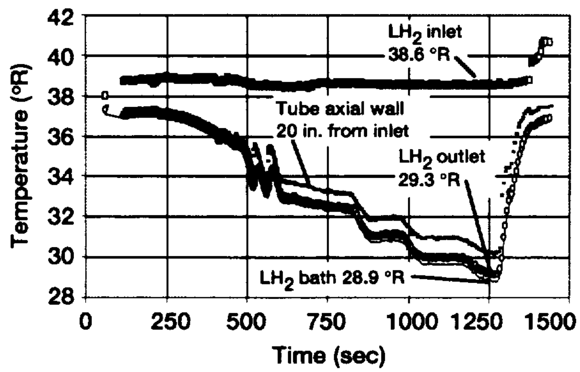


Figure 27.—Heat exchanger LH_2 inlet, axial wall, outlet and bath temperatures during hydrogen densification Test H4.

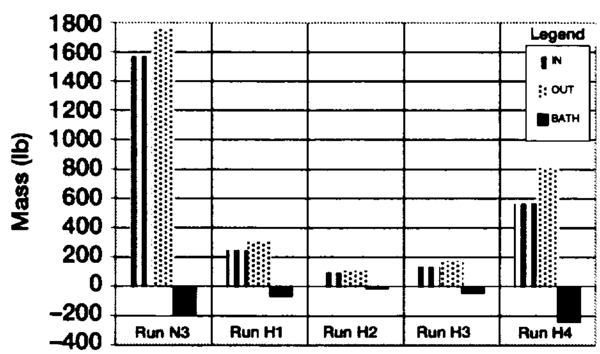


Figure 28.—Heat exchanger mass balance test results for LN_2 and LH_2 densification runs.

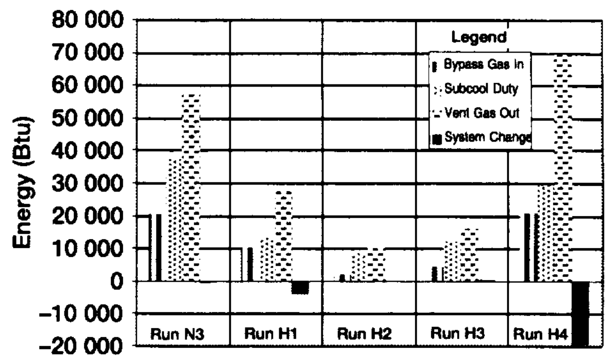


Figure 29.—Heat exchanger energy balance test results for LN_2 and LH_2 densification runs.

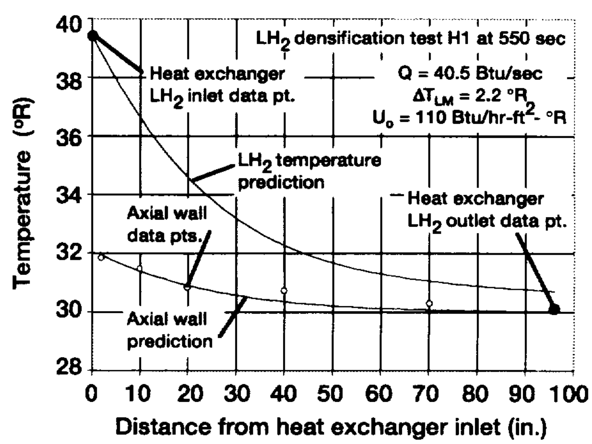


Figure 30.—Heat exchanger axial wall and LH_2 outlet temperature data compared to analytical model predictions.

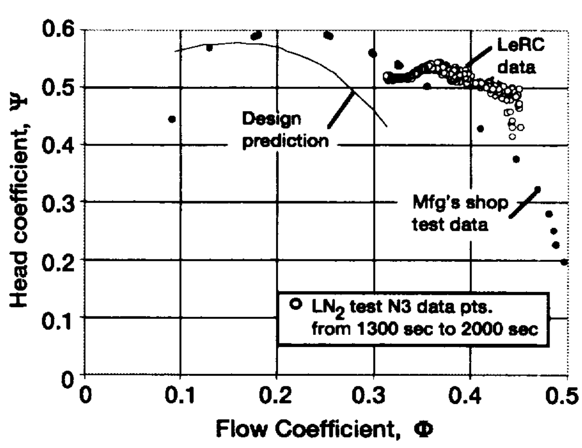


Figure 31.—Compressor stage 1 experimental head versus flow coefficient during LN_2 densification test N3.

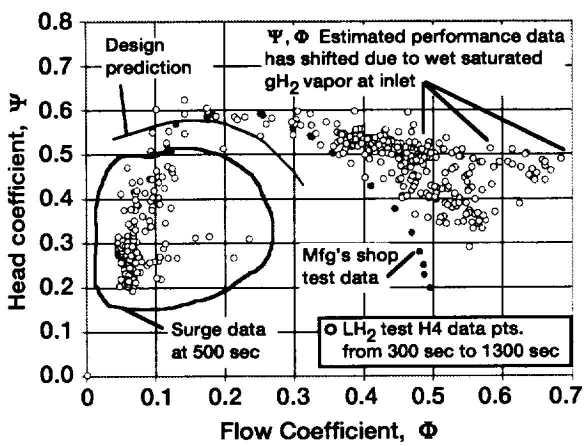


Figure 32.—Compressor stage 1 head versus flow coefficient for LH_2 densification test H4 assuming dry inlet gH_2.

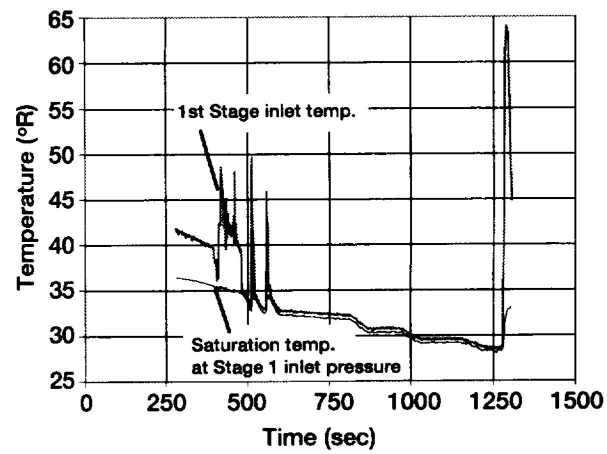


Figure 33.—Compressor 1st stage inlet gH_2 temperature compared to hydrogen saturation temperature during LH_2 Test H4.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 1997	Technical Memorandum

4. TITLE AND SUBTITLE

Performance Tests of a Liquid Hydrogen Propellant Densification Ground Support System for the X33/RLV

5. FUNDING NUMBERS

WU-242-33-01

6. AUTHOR(S)

Thomas M. Tomsik

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135-3191

8. PERFORMING ORGANIZATION REPORT NUMBER

E-10737

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA TM-107469
AIAA-97-2976

11. SUPPLEMENTARY NOTES

Prepared for the 33rd Joint Propulsion Conference & Exhibit cosponsored by AIAA, ASME, SAE, and ASEE, Seattle, Washington, July 6–9, 1997. Responsible person, Thomas M. Tomsik, organization code 5870, (216) 977–7519.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Category 28

This publication is available from the NASA Center for AeroSpace Information, (301) 621–0390.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

A concept for improving the performance of propulsion systems in expendable and single-stage-to-orbit (SSTO) launch vehicles much like the X33/RLV has been identified. The approach is to utilize densified cryogenic liquid hydrogen (LH_2) and liquid oxygen (LOX) propellants to fuel the propulsion stage. The primary benefit for using this relatively high specific impulse densified propellant mixture is the subsequent reduction of the launch vehicle gross lift-off weight. Production of densified propellants however requires specialized equipment to actively subcool both the liquid oxygen and liquid hydrogen to temperatures below their normal boiling point. A propellant densification unit based on an external thermodynamic vent principle which operates at subatmospheric pressure and supercold temperatures provides a means for the LH_2 and LOX densification process to occur. To demonstrate the production concept for the densification of the liquid hydrogen propellant, a system comprised of a multistage gaseous hydrogen compressor, LH_2 recirculation pumps and a cryogenic LH_2 heat exchanger was designed, built and tested at the NASA Lewis Research Center (LeRC). This paper presents the design configuration of the LH_2 propellant densification production hardware, analytical details and results of performance testing conducted with the hydrogen densifier Ground Support Equipment (GSE).

14. SUBJECT TERMS

Propellant densification; Subcooled cryogens; Densified liquid hydrogen

15. NUMBER OF PAGES

41

16. PRICE CODE

A03

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

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102