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Advanced Liquid Oxygen (LO_2) Propellant Conditioning Concept Testing

G.L.E. Perry, J.D. Suter, and S.G. Turner
Marshall Space Flight Center • MSFC, Alabama

National Aeronautics and Space Administration
Marshall Space Flight Center • MSFC, Alabama 35812

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ADVANCED LIQUID OXYGEN (LO_2) PROPELLANT CONDITIONING CONCEPT TESTING

BACKGROUND AND APPROACH

The concept of propellant conditioning is applied to systems to provide proper propellant temperatures required for engine ignition while preventing geysering in the propellant feedlines. During the design process for the National Launch System (NLS), several propellant conditioning concepts for liquid hydrogen (LH_2) and liquid oxygen (LO_2) were evaluated. The purpose of the evaluation was to investigate promising propellant conditioning options that would increase reliability and operability and simultaneously reduce costs of future advanced launch vehicles. Several trade studies were conducted for the evaluation, examples of which are summarized in references 1 and 2. These studies showed that no-propellant bleed through the engine (passive recirculation) is the best conditioning option for both LO_2 and LH_2, followed by low-bleed rate through the engine, helium (He) injection into the engine feed duct, and use of a recirculation line on the feed duct.

The current shuttle system uses a high propellant bleed rate (6.0 lbm/s) through the engine to maintain cold oxidizer temperatures at the engine interface. The high bleed rate requires hardware such as valves, disconnects, and ducting. This hardware can be manpower intensive because it may require preflight maintenance and checkout and thus increase onpad operations, failure hazards, and alterations to flight schedules. Consequently, more manpower and hardware requirements increase costs. Reducing or eliminating bleed requirements may help in improving the reliability, operability, and cost effectiveness of future launch vehicles. In addition, large amounts of propellant necessary for conditioning a high-bleed system will be reduced when incorporating either a passive recirculation or a low-bleed system.

Marshall Space Flight Center (MSFC) participated in a Joint Independent Research and Development (JIRAD) project with General Dynamics Space Systems (GDSS) to evaluate several concepts of LO_2 propellant conditioning with emphasis on no-propellant bleed through the engine. The project was conducted between October 1992 and January 1994. (Evaluation of the LH_2 propellant conditioning concept testing has been done previously in a JIRAD between MSFC and Rockwell International.[3]) Other concepts studied in the LO_2 JIRAD were low-bleed rate, He injection, and use of a recirculation line. These options were evaluated for their feasibility in the event that the no-bleed concept could not adequately condition the propellant.[4]

A precursor to this JIRAD involved water testing with several one-quarter scale test articles. This work was conducted at the University of California at San Diego in early 1992 independently by GDSS.[5] The water testing allowed some initial assessment of fluid behavior and verification (anchoring) of models for LO_2 conditioning. While this testing proved valuable, it did not simulate all the pertinent parameters of cryogenic fluid conditioning. Full-scale testing and anchoring of analytical models with actual cryogens were needed.

The vehicle concept used for the MSFC/GDSS JIRAD project was the NLS, and the test articles simulated the sustainer and booster configurations. The sustainer and booster feed ducts are shown in figure 1. While the project was originally directed toward the NLS design baseline, the parameters studied address generic heavy lift type vehicles that have been discussed in recent years. The design data base, which contains data from all four propellant conditioning concepts, is anticipated to be valuable to many future heavy lift type vehicles including the Atlas IIB and the single-stage-to-orbit (SSTO) vehicle.

Two full-scale feedline test articles were provided by GDSS for testing. The articles, which simulated propellant engine feed ducts, had slopes of 25° and 15°, respectively, which were the maximum and minimum slope limits adopted for the original NLS design. A section, which simulated heat input from a LO_2 turbopump, was attached to the bottom of each test article. Figure 2 shows details of the test articles used for this project.

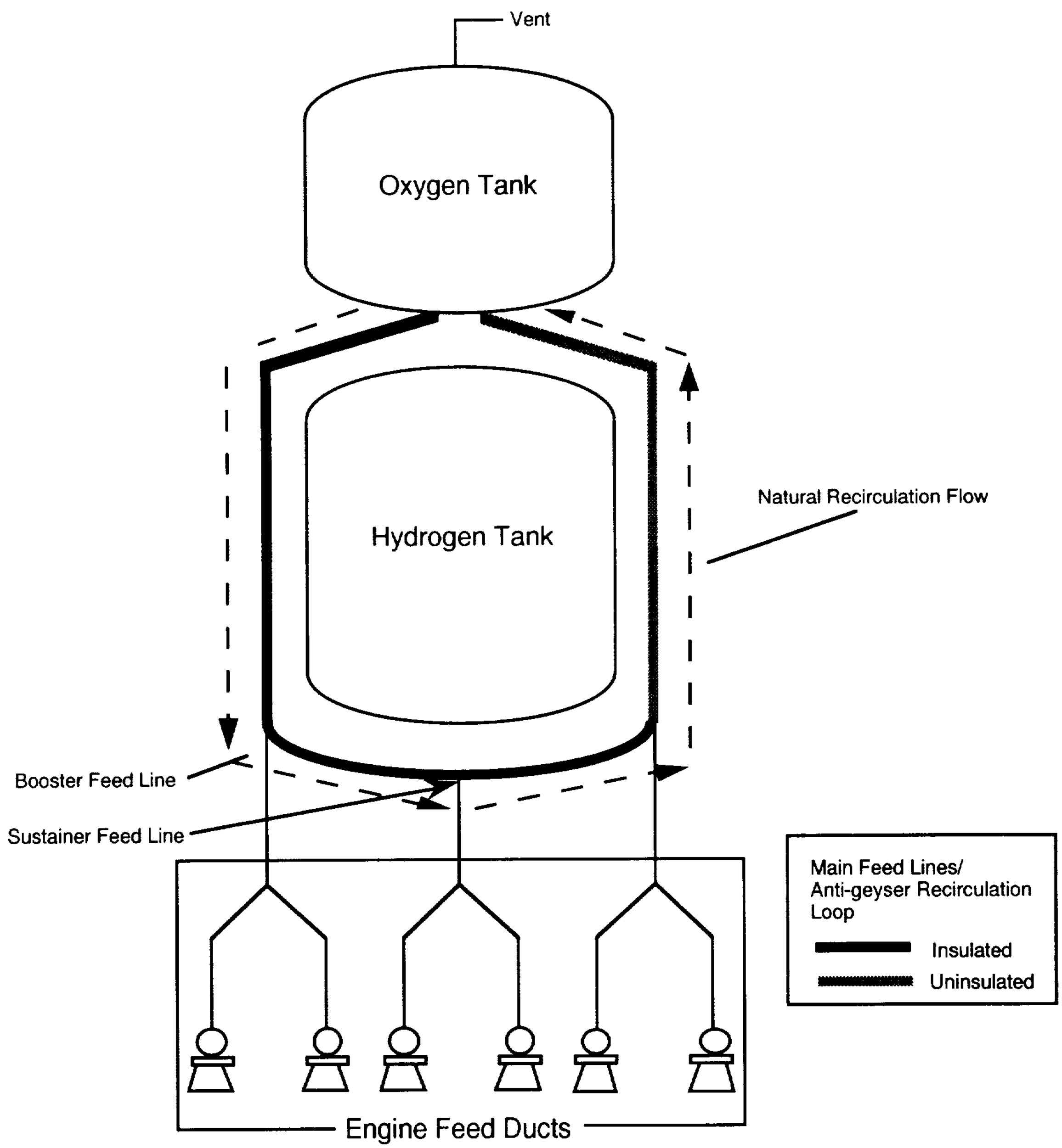


Figure 1. Diagram of a heavy lift launch vehicle, main propulsion system.

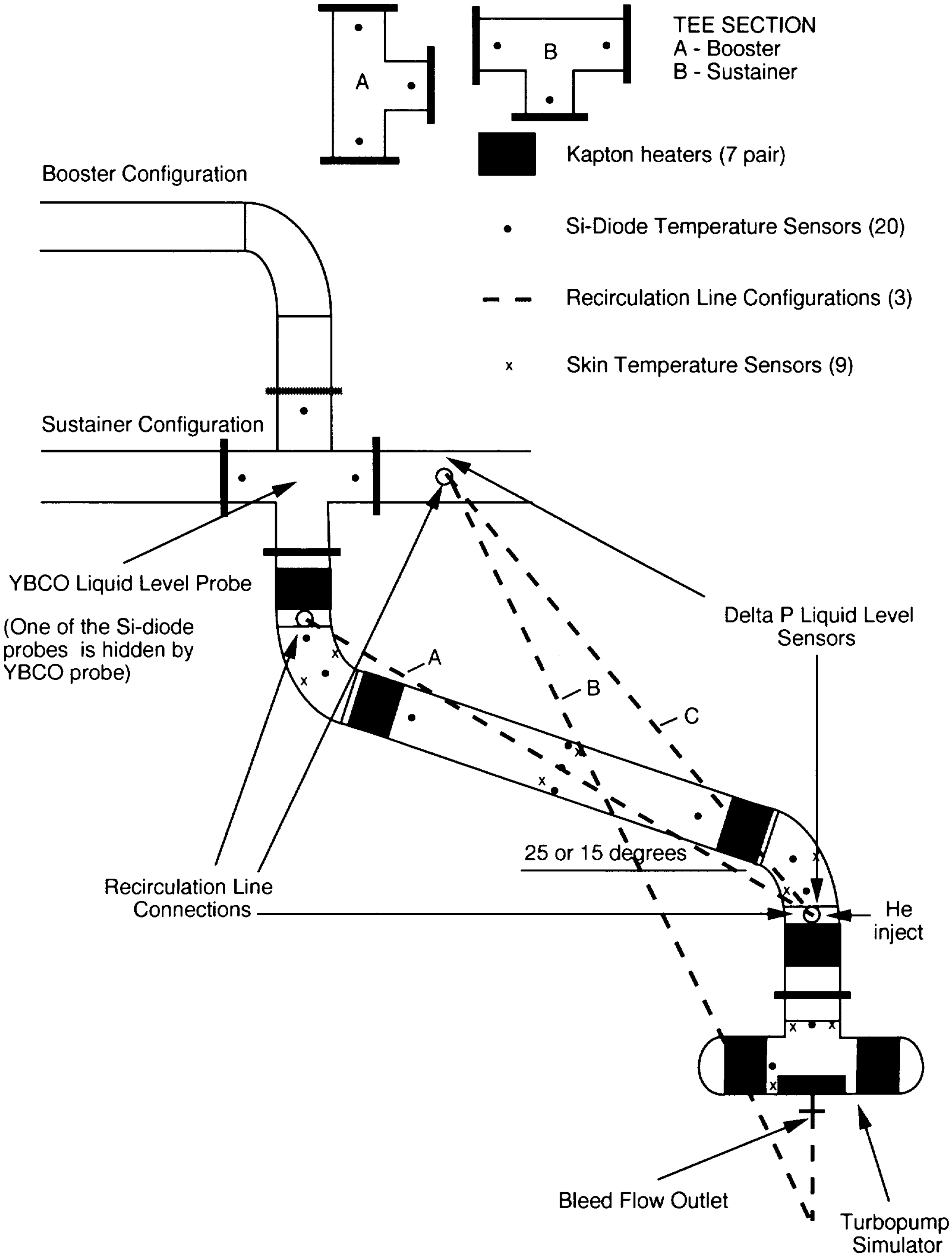


Figure 2. Detailed drawing of the test article used in the LO_2 propellant conditioning test project. (Each article was constructed of 6061 12-in inside diameter aluminum (0.375-in wall).)

PROJECT OBJECTIVES

The objectives of this project were to validate and anchor analytical feedline models and to demonstrate the feasibility of no-bleed conditioning. While earlier trade studies showed that the no-bleed concept was the best option, there were conflicting model predictions of turbopump inlet temperature and pressure conditions. The test data would be used to anchor analytical models and generate design guidelines for the development of a main propulsion feed system.

Liquid nitrogen (LN_2) was used for testing rather than LO_2 for safety and operational concerns, but it provides very similar fluid properties, heat fluxes, and flow velocities to that of LO_2.

CONDITIONING CONCEPTS

Two areas of interest for this project were the temperature and pressure at the engine interface and the flow conditions within the engine feed ducts. The outer loop of the NLS design has two main feedlines which are connected by a main recirculation line (fig. 1). These feedlines are subjected to heat loads from the ambient environment. The downcomer feedline of the main recirculation loop is insulated more than the upcomer, causing thermal gradients. These gradients promote natural recirculation in the loop, and thus cold propellant flows continuously out of the tank and through the feedlines. At the same time, the propellant absorbs heat and recirculates back to the tank. Removing the heat provides subcooling in the main feedlines for meeting pump operation requirements.

Unlike in the main feedlines, the flow in the engine feed ducts is not recirculated to the propellant tank. The fluid in the duct is therefore subjected to heat loads from the engine and ambient environment. The predominant heat transfer mechanism in an engine feed duct is through natural convection. The flow in the main recirculation loop causes shear instabilities to develop in the engine feed duct. These instabilities subsequently cause a series of circulation cells, and these cells are believed to enhance the transfer of heat upward through the duct.[4]

Before this project was undertaken, there were unvalidated analytical models and conflicting temperature profiles of conditions at the engine interface for the no-bleed concept. Computational fluid dynamics (CFD) models showed much cooler temperature profiles than one-dimensional (1–D) models for conditions at the engine interface (fig. 3). Also, CFD modeling showed that net positive suction pressure (NPSP) requirements were met without bleeds and a pre-ignition ullage pressure of 20 psig. One-dimensional modeling showed that NPSP requirements were met without bleeds but with a pre-ignition ullage requirement of 60 psig. The higher pressure results in a 3,500 lbm payload reduction.

The low-bleed conditioning concept was ultimately adopted as the cycle 1 baseline for the NLS system, and the established bleed rate of 0.5 lbm/s would be less than the current shuttle system. (Cycle 0 had adopted the no-bleed concept as the NLS baseline.) However, there were also invalidated models within this low bleed range.

Model validation was also required for the last two backup concepts studied. The principles of these two options are described as follows. He injection is used to cool the propellant by removing heat through evaporation of the LO_2 into the He bubbles. A recirculation line is used to provide a path which transports the warmer liquid upward. The downward flow of cooler liquid into the engine feed duct replaces the warm propellant flowing upward through the recirculation line. Figure 4 is a pictorial description of all four conditioning concepts.

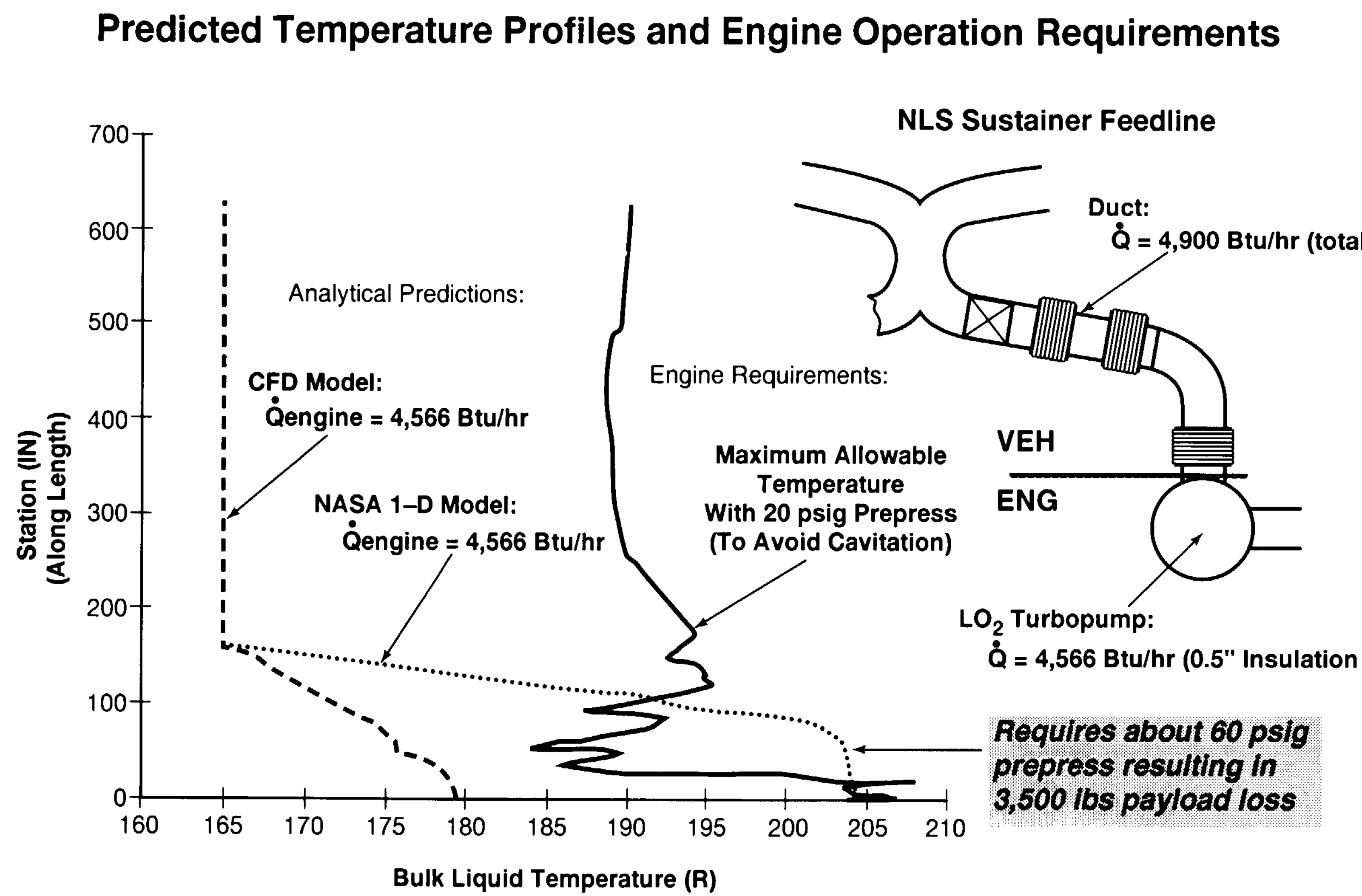


Figure 3. Temperature profiles for 1–D and CFD no-bleed model predictions.

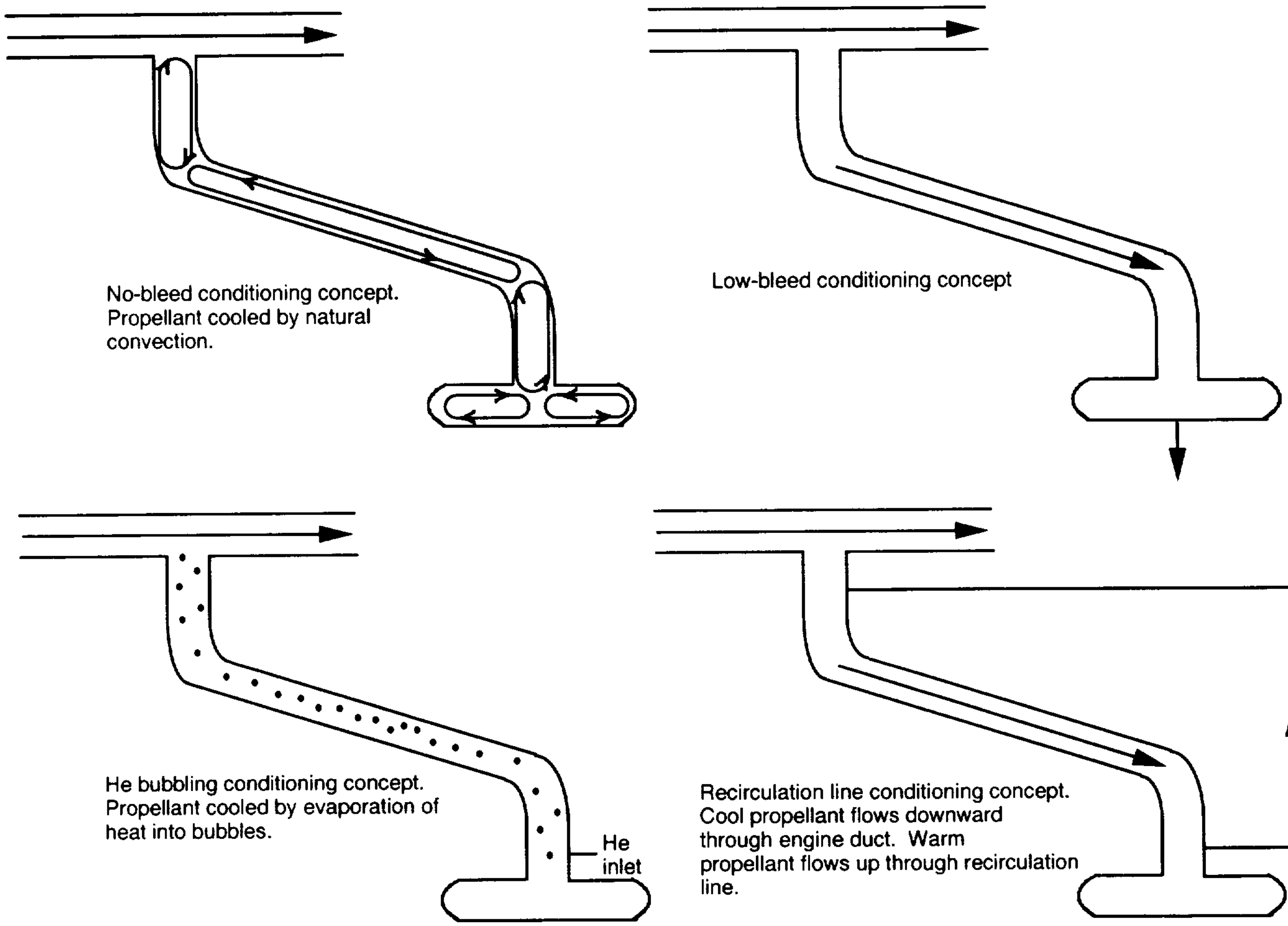


Figure 4. Propellant conditioning concepts.

HEAT LOAD CALIBRATION CHECKS

Since heat input to the feed duct was one of the most significant parameters to be tested, heat load calibration checks were performed on the test article prior to the start of overall testing. Because of variations in environmental conditions, variations in insulation thicknesses on the test article, and uncertainty in heat transfer coefficients, analysis alone could not sufficiently quantify heat inputs to the article. Therefore, conducting heat load calibration checks were important.

Heat load calibrations were performed on the 25° and 15° sloped feedlines and on the separate turbopump simulator section. Kapton™ heaters simulated heat loads present at the prevalve, flex joints, and turbopump section of the test article. Heat leak from the test article was quantified by measuring the rate of gaseous nitrogen (GN_2) boiloff in actual cubic foot per minute with a gas flowmeter. The results from these calibration tests helped determine the heater settings for the heat load values in the test matrix.[6]

PHASES OF TEST PROJECT

The JIRAD testing was conducted in two different phases. The first full-scale tests conducted under this JIRAD comprised a feasibility check which involved the 25° sloped test article in the sustainer mode. All four concepts of no-bleed, low-bleed, He injection, and use of a recirculation line were tested in this phase. This particular phase was intended to assure that results from all four conditioning concepts could be obtained. Also, the parameters tested at this time were baseline values of pressure, temperature, velocity, the intended range of bleed flows, and all three recirculation line configurations.

The next phase of testing involved studying the impact of design parameters. This phase included but was not limited to testing the 25° article in the booster configuration and the 15° article in the sustainer mode. Table 1 shows a layout of the parameters tested in this project.

Table 1. Parameters and levels tested for the LO_2 propellant conditioning test project (the bold level values were those tested during the feasibility check phase).

Parameters	Level
Slope	**25°**, 15°
Configuration	**Sustainer**, Booster
Side Heating	**2,500 Btu/h**, 4,500 Btu/h
Bottom Heating	**3,000 Btu/h**, 5,500 Btu/h
Velocity	**1.5 ft/s**, 1 ft/s
Pressure	**100 lb/in^2 absolute**, 60 lb/in^2 absolute
Helium Bubbling	**0 lb/s**, 0.005 lb/s
Bleed Rates	**0.0, 0.3, 0.5, and 1.0 lb/s**
Recirculation Line	
A Before Pump	**2 in**
B After Pump	**2 in**
C Before Pump—Alternate	**2 in**

TEST MATRIX DEVELOPMENT

A design of experiments type test matrix of over 100 tests was developed to test all four propellant conditioning concepts. All four conditioning concepts were tested with the 25° sloped article in the sustainer mode. The 25° article was also tested in the booster configuration while the 15° article was tested solely in the sustainer configuration. Recirculation line tests were not repeated with the 25° booster or 15° sustainer configurations. The booster tests were also not repeated with the 15° article. Analysis revealed that the data from these tests would not provide additional information to the data already obtained with these applications in the 25° sustainer configuration.

TEST FACILITY

The facility used for testing was the liquid hydrogen cold flow (HCF) facility of the WTA of MSFC. The facility layout simulated the tank, outer flow loop, and feedline configuration of the NLS and other generic heavy lift type vehicles. Figure 5 gives a general layout of the facility. A 10,000 gal storage tank was used which served as a reservoir for the LN_2. The LN_2 was gravity fed from the tank to a 600-gal/min circulation pump. This pump was used to simulate the velocity conditions across the top of the test article. The propellant was pumped to the test article then back to the tank. Figure 6 shows a more extensive picture of the layout of the facility. Flowrates were controlled by three variable position valves (VPV's) in the delivery and return lines from the tank. The three valves were fitted with variable position operators resulting in a wide variety of flow rates. Other valves included a 6-in tank vent valve which was used to relieve pressure in the tank, a pair of vent valves for relieving pressure in the facility, and valves which allowed the test article to be filled from the bottom. Filling the test article gradually from the bottom did not jeopardize its internal instrumentation.

Tubing of 1-in stainless steel was used to deliver 500 lb/in^2 of GN_2 for tank pressurization, as well as to direct GN_2 boiloff from the test article during heat leak calibration tests. Tubing was also used to route GN_2 and LN_2 through redundant gas and liquid turbine flowmeters. All other piping used in the facility was welded schedule 10 stainless steel pipe. Two-phase flow through the gas flowmeters was avoided by using an external heater on the vent line exiting the test article. For low-bleed measurements, two-phase flow was prevented by using a heat exchanger on the bleed line to condense any GN_2.

The two test articles used in this project were of 12-in diameter 6061-T6 aluminum pipe. To simulate feedline geometry, the test article slopes used were 25° and 15°, respectively, but the turbopump simulator was the same for each slope used. The article was flanged to the main loop of the facility with a tee section and three 150-lb flanges. The tee section was turned 90° from the sustainer configuration to accommodate the booster type setup. Kapton heaters were used to simulate heat loads in the test article at the prevalve, elbows, and turbopump simulator.

The entire test article was insulated. The sloped line and turbopump simulator were insulated with two-component 2.7-lbm/ft^3 Polythane Systems, Inc. (PSI) S200-27 polyurethane spray-on foam. Two-component, 3-lbm/ft^3 polyurethane pour-on foam was used on all flanged joints and the facility tee where the feedline was joined to the facility. The pour-on foam was used at its particular locations because access to these sections was required more frequently, and it was more feasible to remove and replace pour foam rather than spray foam. Finally, a mastic coating was applied as a barrier to inhibit breakdown of the spray-on foam by both ultraviolet exposure from the Sun and moisture.

Instrumentation was used for taking measurements for both the facility and the test article. Nineteen Taber-type transducers monitored the pressure in the facility and test article. Type "E" thermocouples and resistance temperature devices (RTD's) were used to monitor the facility temperatures while silicon-diode (Si-diode) temperature sensors were used for measuring the temperature profile within the feed duct. Liquid levels in the run tank and test article were indicated by data from delta pressure transducers.

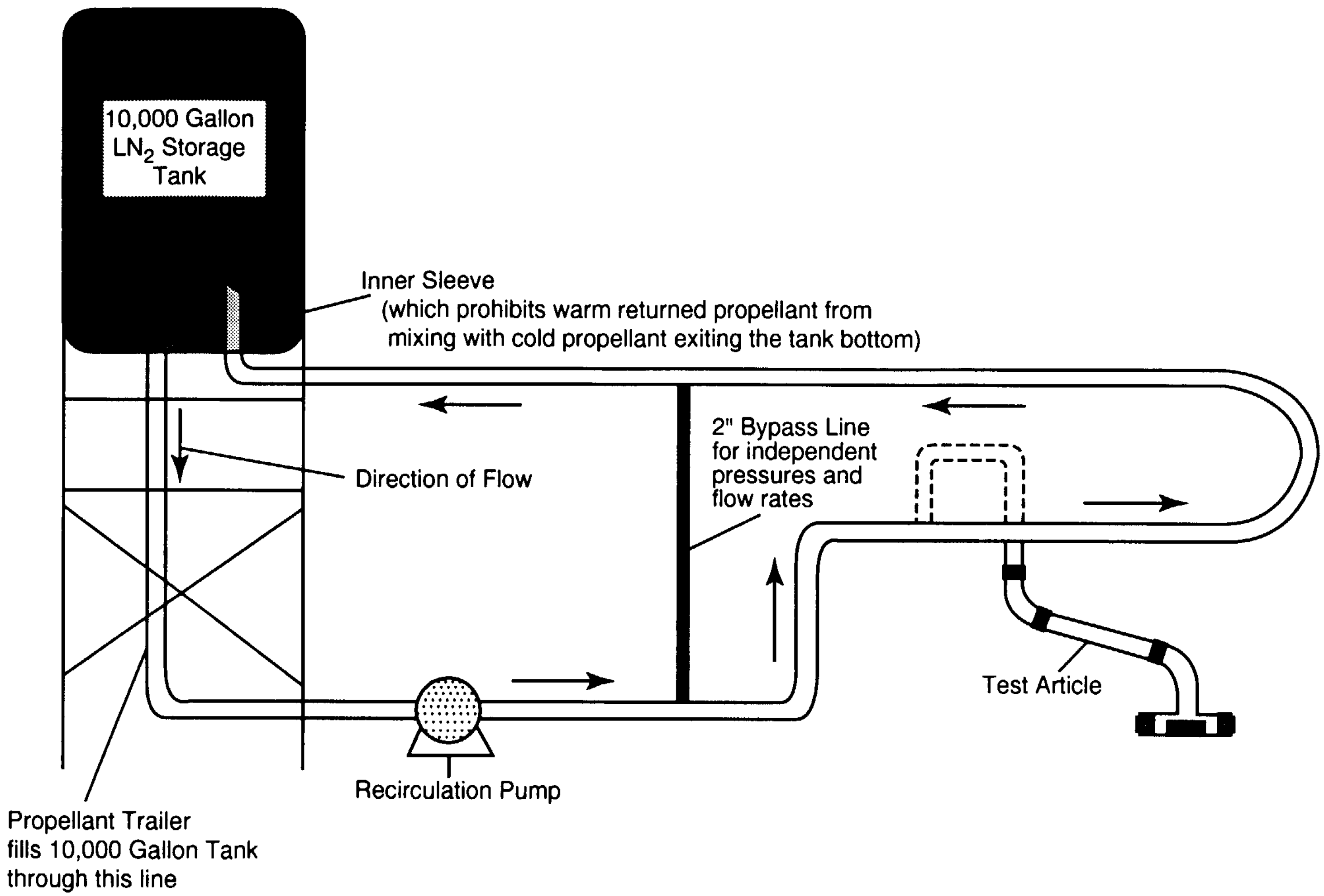


Figure 5. General test schematic for the LO_2 propellant conditioning project at the liquid hydrogen cold flow facility in the west test area of MSFC. Note that this figure is not to scale.

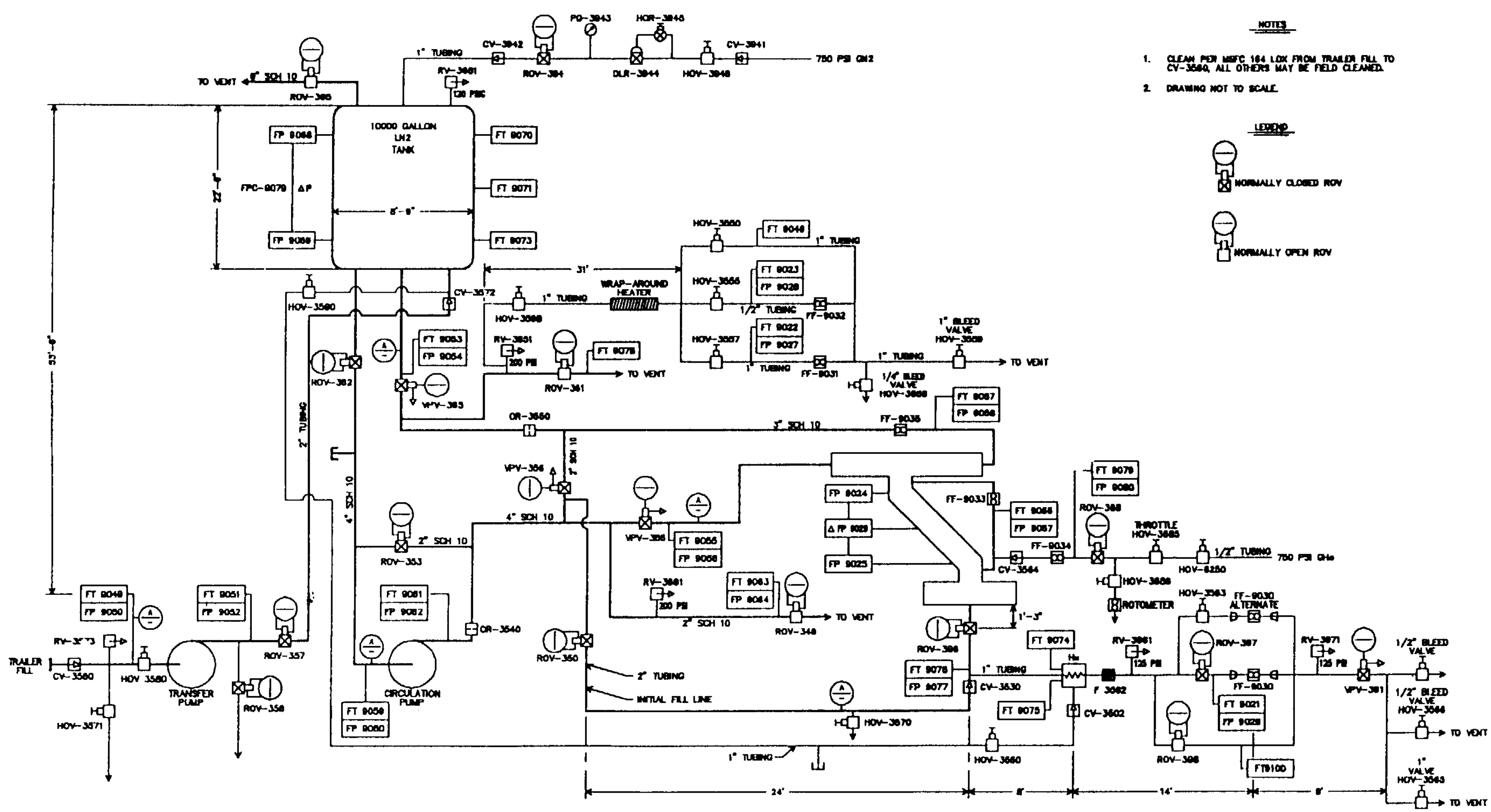


Figure 6. Detailed drawing of the test schematic of the LO_2 propellant conditioning project at the HCF facility in the WTA of MSFC.

TEST OPERATION

A typical test operation would begin with LN_2 transferred from tanker trucks to the 10,000-gal run tank (fig. 6). A propellant tanker truck was pressurized to 30 lb/in^2 gauge to provide a positive pressure to the transfer pump. Hand-operated valve (HOV) 3580 was opened to allow liquid to flow through remote-operated valve (ROV) 358 thus giving the transfer pump time to chill. When temperature transducers FT 9049 and FT 9051 indicated the pump was chilled, ROV 358 was closed and ROV 357 was opened, and the propellant transfer pump was turned on. It usually required three propellant trucks (a propellant truck contains 4,000 gal of propellant) to fill the run tank. Once the run tank was filled, the lower vent ROV 349 was closed and variable position valve (VPV) 391 was adjusted to the closed position. ROV 362 was then opened to chill the facility piping. No LN_2 entered the pump inlet until VPV 391 was adjusted to the open position; opening VPV 391 reduced pressure in the propellant lines which allowed LN_2 to flow and displace the purge gas within the lines. When the temperature transducer, FT 9076, indicated a near-liquid temperature (approaching 140 °R), the tank vent valve, ROV 395, was closed. Closing ROV 395 increased the system pressure, thus encouraging the flow of liquid. Next, the test article was filled through the bottom by opening ROV 396. While filling the test article, the system was bleeding liquid through VPV 391 and venting gas through the upper vent ROV 361. Progress on filling the test article was monitored in the control room of the WTA by observing the FT 9057 temperature and FP 9025 pressure transducers. When FT 9057 indicated a near-liquid temperature, VPV 366 preceding the test article was opened 10 percent. When FT 9078 indicated a liquid temperature, ROV 361 was closed. Finally, the vertical portion of the return piping to the run tank was filled by opening VPV 365 10 percent. When the pressure upstream of the test article (indicated by FP 9058), was within 4–5 psig of the tank pressure (indicated by FP 9069), both VPV's 366 and 365 were fully opened. If low bleed measurements were to be taken, ROV 396 was left in the open position. Otherwise, for all other tests, this valve was closed.

When the test article and connecting piping were filled with liquid, the tank vent ROV 395 was opened and the circulation pump started. By adjusting VPV's 356, 365, and 366 in the supply and return lines, the prescribed flow rate and pressure in the test article were obtained. Since the liquid level in the tank gradually dropped because of evaporation, the valve positions had to be continuously adjusted to maintain the desired flow rate. The liquid level in the run tank was replenished during long-duration test days by unloading additional propellant trucks as necessary.

During the low-bleed phase of the testing, ROV 396 was opened at the bottom of the test article. Opening this valve routed LN_2 to a 1/2-in flowmeter, FF 9030. (An alternate 1/2-in flowmeter was also installed as backup.) A bypass loop around the flowmeters allowed the delivery lines to chill by opening and closing ROV's 398 and 397, respectively. This chilling procedure prevented damage to the instrumentation. VPV 391 installed near the discharge of the flowmeters was adjusted to obtain the desired bleed flow rate. Small HOV's 3565 and 3566 installed upstream of VPV 391 were also used to adjust bleed flow rates as needed.

For He injection tests, gaseous He was introduced by a 1/2-in line to the feed duct centerline through a 2-in flange located near the bottom of the test article. HOV 6250 was opened which put 750 lb/in^2 of pressure against the throttle valve HOV 3685. HOV's 3685 and 3686 were then opened to establish flow within 5 to 10 percent of prescribed values. During actual He injection testing, ROV 368 was opened and the flow rate was fine tuned by adjusting HOV 3685. He flow was verified through flowmeter FF 9034. Flow rates in the recirculation line were monitored by flowmeter FF 9033 which used a radio frequency pickup (instead of magnetic pickup) to reduce drag.

Heater settings for all tests were adjusted remotely by monitoring the voltage, amperage, and wattage delivered to each of three heater zones located on the test article. Zone 1 consisted of the upper two pairs of heaters on the test article, zone 2 consisted of the lower two pairs of heaters on the test article, and zone 3 consisted of the three pairs of heaters on the turbopump simulator section.

At the end of each test day, errors in the Si-diode temperature sensors were measured by isolating the test article from the facility and allowing the article to be slowly drained. In the beginning of the project, some of the sensors appeared to have failed, as was indicated on the data screens which were being monitored in the test control room. Some sensors were obviously not measuring at all, while some sensors were close but still a few degrees off the expected temperature. To test the integrity and accuracy of the probes, at the end of each test day, the test article was filled completely with LN_2 and brought to the saturation temperature of LN_2 based on the operating pressure. The article was isolated from the facility by closing VPV's 356, 365, and 366, then slowly drained by opening ROV 396 and letting the propellant bleed through the small HOV 3566. It could be determined from monitoring the data when a temperature sensor went "dry," i.e., by comparing the reading of a "dry" sensor with the saturation temperature as the article was being drained. The "dry" readings could also be verified by calculated liquid level based on the data obtained with the delta P sensors mentioned previously. Although not used during drain tests, skin temperature thermocouples were another method used to verify readings from the Si-diode probes. Nine skin temperature probes were attached to the test article under its insulation (fig. 2). While the skin temperature sensors were not as sensitive as a Si-diode probe (which, when operating correctly, could measure within ± 0.15 K), the thermocouples were nonetheless able to provide an estimate of the cryogenic temperature in the feed duct within a few degrees of the actual temperature.

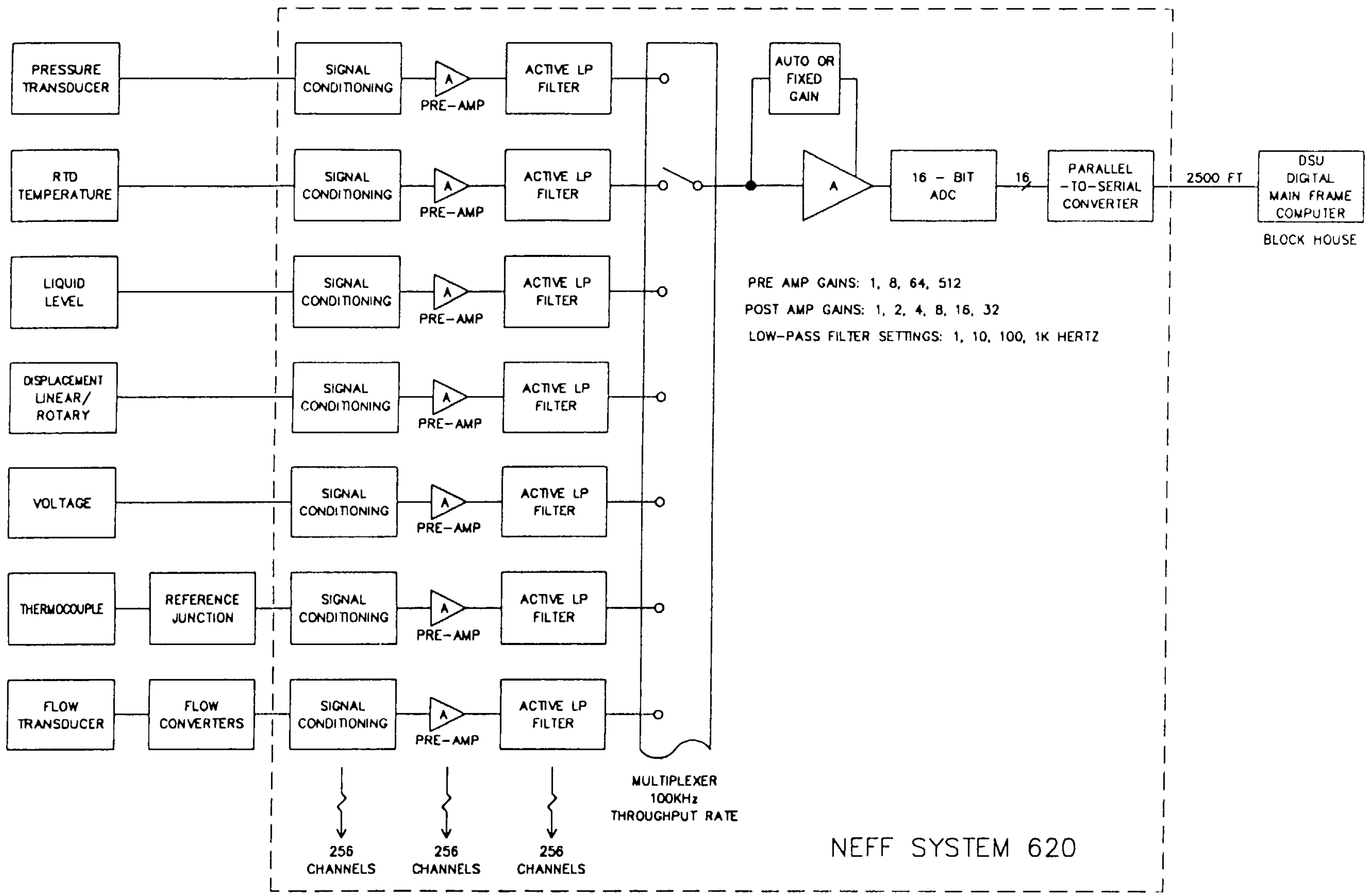
To secure the facility, the run tank inlet and outlet valves, ROV 362 and VPV 365, were closed and the facility and test article were drained. To prevent moisture from entering the system, GN_2 purges were initiated which concluded the day's operations.

DATA ACQUISITION SYSTEM

The data acquisition system consists of both a large mainframe digital computer, referred to as the data select unit (DSU), and one or more front-end data acquisition subsystems, called signal input units (SIU's). The SIU's are located as close as possible to the test article to provide proper conditioning of the analog signal from the transducers before being digitized and sent to the DSU. The DSU performs the important function of recording the digital data on magnetic tape and provides real-time displays of the data in engineering units. The combination of these two systems allows the user to have high channel capacity, versatility, and large data storage capability.

A NEFF System 620 is currently being used as an SIU. Each NEFF system has a 256-channel capacity, with each channel providing signal conditioning, filtering, and amplification. The systems are controlled by microprocessors which direct the internal system calibration, transducer calibration, filter setting, gain settings, and sample rate commands. Data from the 256-channel inputs are multiplexed with a maximum throughput of 100 kHz, then digitized by a 16-bit analog to digital converter (fig. 7). The data are then transmitted several thousand feet where they are stored and displayed to the user.

The DSU uses two 16-bit microprocessors to accomplish all of the storage and display requirements, and can handle up to 1,000 measurements. Sample rates can be varied from 20 ms to 60 s. A maximum of 8 real-time screens can simultaneously display 104 measurements with the ability to indicate calculated measurements as well as out-of-limit flags to the user. All digitized data are stored on



NOTE:
SIGNAL CONDITIONING PROVIDES CONSTANT VOLTAGE OR CURRENT EXCITATION, BRIDGE COMPLETION, CALIBRATION SHUNT RESISTORS AND PROGRAMMABLE CALIBRATION.

Figure 7. HCF data acquisition system.

data tapes in raw millivolts. The data are then sent to the processing center where they can be accessed by a local area network or in the form of data plots.

The data obtained in this JIRAD are available to the public through the Perkin-Elmer 4 system at MSFC.

CONTRIBUTIONS BY THE JIRAD PARTICIPANTS

The MSFC and GDSS participants each made special contributions to the project. MSFC provided the WTA HCF facility, all facility instrumentation, LN_2 propellant, and data acquisition equipment. GDSS provided the full-scale 15° and 25° test articles. MSFC fabricated all piping necessary to satisfy the design of the project. To start the project, a memorandum of understanding (MOU) which described legal obligations of the project participants was necessary. The MOU required signatures from the head officials of GDSS and MSFC. An extensive project plan submitted by MSFC, which included scope of work, schedule, and manpower estimates, was also required to begin funding this project.

ANALYSIS

MSFC 1–D and GDSS CFD analysis personnel have been comparing pretest predictions to the actual test data. The test data have shown that satisfactory temperatures are being obtained for the no-bleed propellant conditioning concept. The 1–D technique used at MSFC is a 1–D two-phase model based on a code called FEEDLINE written at MSFC.[7] The CFD technique uses the Flow 3–D code developed by Flow Science, Inc. The model is 2–D with κ - ε turbulence parameters anchored with water test data.

Detailed information on the data trends for all propellant conditioning options can be found in reference 8. More on the GDSS CFD work for all conditioning options can be found in references 9 and 10.

TECHNOLOGY APPLICATIONS

In addition to the basic merits of this JIRAD, the project fostered technology applications which were employed to obtain the valuable data of all the propellant conditioning concepts. An example of an application was the use of Si-diode temperature sensors in the test article to indicate the temperature profile within the feed duct. These sensors had never been used in this type of application previously, and, when operating correctly, provided a very high degree of accuracy of ±0.15 K. However, as described previously, there were some problems in the consistent performance of the probes. The probes were not necessarily durable, and their inconsistency of performance may have depended on how the Si-diode chips were incorporated into the probe. Upon conferring with the probes' vendor, it was discovered that these sensors were made of dissimilar materials, which consequently caused nonuniform expansion and contraction during temperature changes. It thus follows that there were irregular temperature readings from some of the probes.

Another application involved a superconducting liquid level sensor constructed of yttrium barium copper oxide (Y-B-C-O). This Y-B-C-O probe was intended for use as a LN_2 level sensor in the test article for heat leak and drain tests. However, the probe did not perform satisfactorily. After doing independent testing on the integrity of the probe, it was discovered that the probe was only calibrated to show resistance at ambient pressures. Part of the theory as to why the probe was not working properly was that the superconducting material may not have been 100-percent pure. Because of the failure of the probe, delta P sensors described in the facility and test operations section were used to detect the liquid level within the test article. While the probe did not perform satisfactorily, it is hoped that its manufacturer will be able to improve the probe's performance so that it will be a useful tool for LN_2 liquid level detection in the future.

A final example of a technology spinoff was the application of the 3M™ adhesive which held the Kapton heaters in place on the test article. The tape was tested independently and successfully for its ability to withstand extreme temperature cycling with LN_2.

CONCLUSIONS AND FUTURE WORK

Based on the analysis to date, the no-bleed propellant conditioning concept may be applied to future heavy lift type launch vehicles such as Atlas IIB and SSTO. Other conditioning projects are currently being pursued to elaborate on the work started in this particular JIRAD. Currently, work under a different program is underway to complete the data base on LO_2 propellant conditioning at the HCF facility. Also, it is anticipated that another facility will be built and fabricated within the next few years at the MSFC WTA that will accommodate actual LO_2 testing.

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13. ABSTRACT *(Maximum 200 words)*

Advanced methods of liquid oxygen (LO_2) propellant conditioning were studied as part of an effort for increasing reliability and operability while reducing cost of future heavy lift launch vehicles. The most promising conditioning concept evaluated was no-bleed (passive recirculation) followed by low-bleed, helium injection, and use of a recirculation line. Full-scale cryogenic testing was performed with a sloped feedline test article to validate models of behavior of LO_2 in the feedline and to prove no-bleed feasibility. Test data are also intended to help generate design guidelines for the development of a main propulsion system feed duct. A design-of-experiments matrix of over 100 tests was developed to test all four propellant conditioning concepts and the impact of design parameters on the concepts. Liquid nitrogen was used as the test fluid. The work for this project was conducted from October 1992 through January 1994 at the hydrogen cold flow facility of the west test area of MSFC. Test data have shown that satisfactory temperatures are being obtained for the no-bleed conditioning concept.

14. SUBJECT TERMS
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APPROVAL

ADVANCED LIQUID OXYGEN (LO_2) PROPELLANT CONDITIONING CONCEPT TESTING

By G.L.E. Perry, J.D. Suter, and S.G. Turner

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

W. R. Humphries

J.P. McCarty
Director, Propulsion Laboratory

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