THE DEVELOPMENT OF AN IR ENVIRONMENTAL SYSTEM FOR TOPEX/POSEIDON SOLAR PANEL TESTING

E. W. Noller
Jet Propulsion Laboratory, California institute of "J'ethnology
Pasadena, California 91109

1. ABSTRACT

Environmental testing and flight qualification of the TOPEX/POSEIDON spacecraft solar panels were performed with infrared (IR) lamps and a control system that were newly designed and integrated. The basic goal was more rigorous testing of the. costly panels' new composite-structure design without jeopardizing their safety, The technique greatly reduces the costs and high risks of testing flight solar panels. The high cost of conventional thermal vacuum testing was the driver for a new approach to qualifying the panels' design. While IR simulation does not substitute for full solar spectrum testing, it has unique characteristics that make adequate, affordable thermal testing possible. The required uniform heat flux distribution of one solar constant or more was produced over the large panel area, The objective of the technique's design and its fixture implementation was the creation of realistic, large thermal transient conditions that would produce large gradients in a panel in real-time simulation. The technique utilizes new technologies and advances in commercial components to simulate realistic thermal conditions while keeping flight hardware safe. The fixture supporting the panels during testing required an unrestrained mechanical suspension system so that panel distortion, caused by thermal change, would not damage the panel structure.

KEY WORDS: Environmental Simulation, Solar Panel, Thermal Testing

2. INTRODUCTION

Environmental testing and flight qualification of the TOPEX/POSEIDON spacecraft solar panels were performed with an infrared (JR) lamp array and a control system that were new] y designed and integrated. (TOPEX is an experiment for the mapping of ocean topography.) This use of this technique significantly reduces both cost and the risk of damage to the panels.

Solar panel verification testing has been a high-cost and high-risk operation because of the composite-structure design and the fragile nature of solar cells that have evolved from solar panels in military and commercial applications and, especially, in power systems for space exploration. The panels are fragile by their nature and require special handling. Also, the requirements have called for larger and larger panel sizes. Testing has been costly because of engineering system design, panel fixtures, operation cost for each new panel design, and the i nherent schedule risk if there is a panel failure. Pane] testing requirements have relied on three major test methods:

- xenon arc lamp systems that are available at a few facilities; however, the solar beam is small and the cost prohibitive for most projects

- the usc of GN_2 and LN_2 panel radiators between solar panels for inducing thermal gradients

- the usc of tungsten-filament lamps, which has been the most widely used system for testing, but whit}] can damage the solar panels because of overheating and flux nonuniformity across the panel face

J]’]. has designed and implemented a new integrated simulation system. The heating source, which is an 1 R lamp array, and the state-of-the-art control system have been developed to a high state of flexibility for real-time cycling and panel safety. The system consists of the lamp array; a test fixture with an unrestrained, mechanical support system for each panel; and a cryogenic (heat exchange) panel that induces thermal gradients throughout each solar panel from the front face to the back side. The walls of the simulator are shrouded in GN_2/LN_2, which cools the face of the panels through the open space in the lamp array. A much-improved testing technique has been created with this integrated system, and the technique has lowered the testing costs of the TOPEX solar panels by reducing the time to perform the multiple cycles of the test program,

JPL started development of a new control system for 1 R lamp sources in preparation for the thermal vacuum testing of the Magellan spacecraft’s composite solar panels, which took place in 1988, and further improved the system for the 1989 Microwave Limb Sounder (M1 .S) testing program, which used calorimeters as control sensors for the first time. The use of a flux-mapping technique was implemented with an IR camera system for TOPEX. The composite solar panels of the TOPEX spacecraft are the largest panels---approaching 9 m^2 in size- to be tested at the 1.aboratory, and the testing program incorporated all the in-house developments from recent projects.

3. TESTING REQUIREMENTS

The following requirements drove the system design for the thermal vacuum testing:

- two solar panels, placed back to back, with a heat-exchanger panel sandwiched between thcm for gradient inducement

- lamp arrays with zone control for regional gradient inducement

- unrestrained panel support, to permit free distortion of the composite panel in plane and out of plane

- handling of panels by the supporting framework, from their stowed position in the shipping container to installation on the thermal vacuum fixture, without handling thcm by hand

- illumination of the panels with a uniformity of 1 0°C or better by means of zone control of the lamps, with a special requirement for border illumination around the panel edges. Thermal transition rate of 1 5°C min./20°C max. from cold to hot and panel temperature delta from front to back of 16°C at least once during the cycle.

- control the lamp array power with a power runaway fail-safe shutoff circuit with a sensing system for using a network of averaging thermocouples for enunciating the panel condition

4. THE SPACE SIMULATOR FACILITY

The thermal vacuum test was conducted in the JPL space simulator, which is 3 m (10 ft.) in diameter by 10 m (38 ft.) high. The chamber is a bottom-loading system using a hydraulic elevator. 'l'he chamber walls arc shrouded with GN_2/LN_2 for temperat ure cent rol and are vacuum pumped by cryogenic pumps and a turbo pump. The chamber's operating pressure during the test was in the area of 106 torr.

5. THE SUPPORT FIXTURE FOR THERMAL VACUUM TESTING

The ground handling of the two solar panels required a special support fixture so that the panels, which weigh approximately S5 kg (120 lbs.) each, would always be supported in a safe, controlled manner. The panel-transportation support system was utilized in the thermal vacuum test (TVT) fixture design: The support frame was connected to the TVT frame so that the panels could be rotated up vertically for the transfer operation. The strong back frame (support frame) used the same four large aperture holes in the panels that are used to suspend the panels from the walking beam with bolts and cables (Figure 1). The panels were transferred

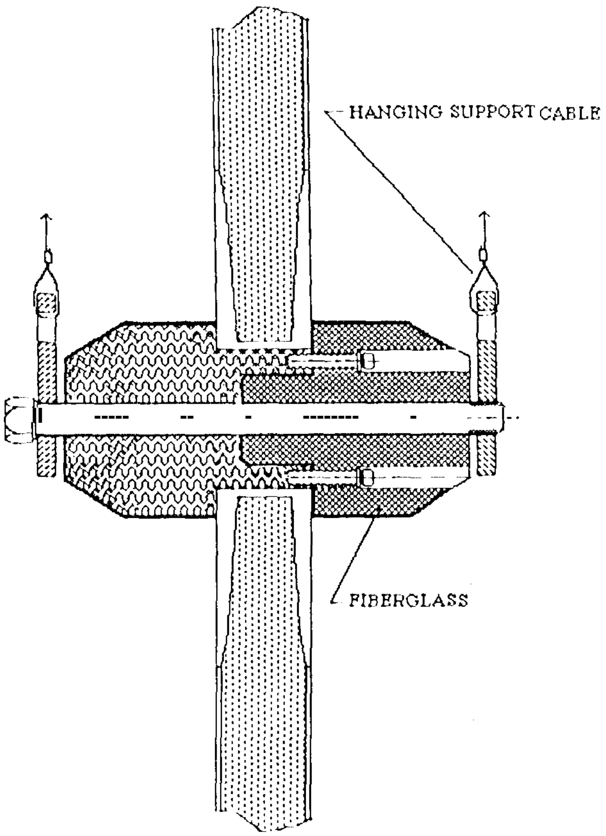

Figure 1. Sectional view of the thermal support hardware for the solar panels.

by an overhead crane; two cables with load cells were connected to two threaded hard points in the top edge of the panels. The pane] transfer was made mechanically and was not hand supported.

The two panels, loaded onto the test support framework, were installed on the chamber's bottom flange between the prc-installed lamp arrays. The test fixture consisted of a basic support framework (J 'igure 2), two primary walking beams for panel support, and a secondary

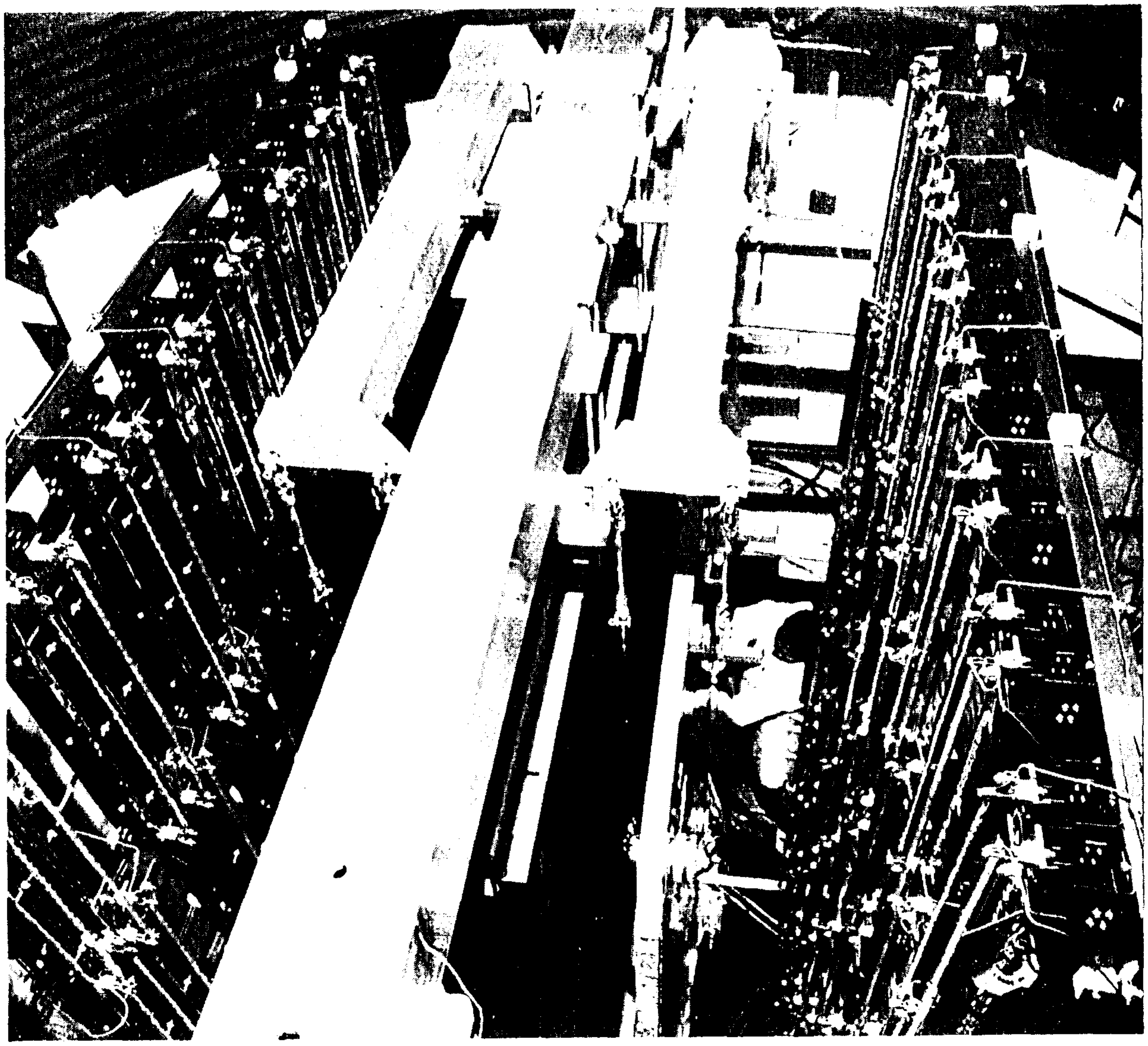

Figure 2. Top view of the thermal support hardware for the solar panels.

walking beam tension system at the bottom of the frame. Located between the panels and centered within the framework was the GN_2/LN_2 heat exchange panel. "l'he. solar panels were held in place by the two primary walking beams, from which they were hung by four cables and which were located cm opposite sides of the top of the framework, and by a constant force spring system at the bottom of the framework. 'l'he support system permitted each solar panel to warp and distort freely under the thermal gradients induced as part of the testing program. The two lamp arrays were installed on the chamber bottom in such a way that the preassembled test package containing the solar panels, cryogenic panel, and all controlling sensors could be rolled into place using an overhead monorail system and transferred to supporting hard points between the lamp arrays (1 'igure 3).

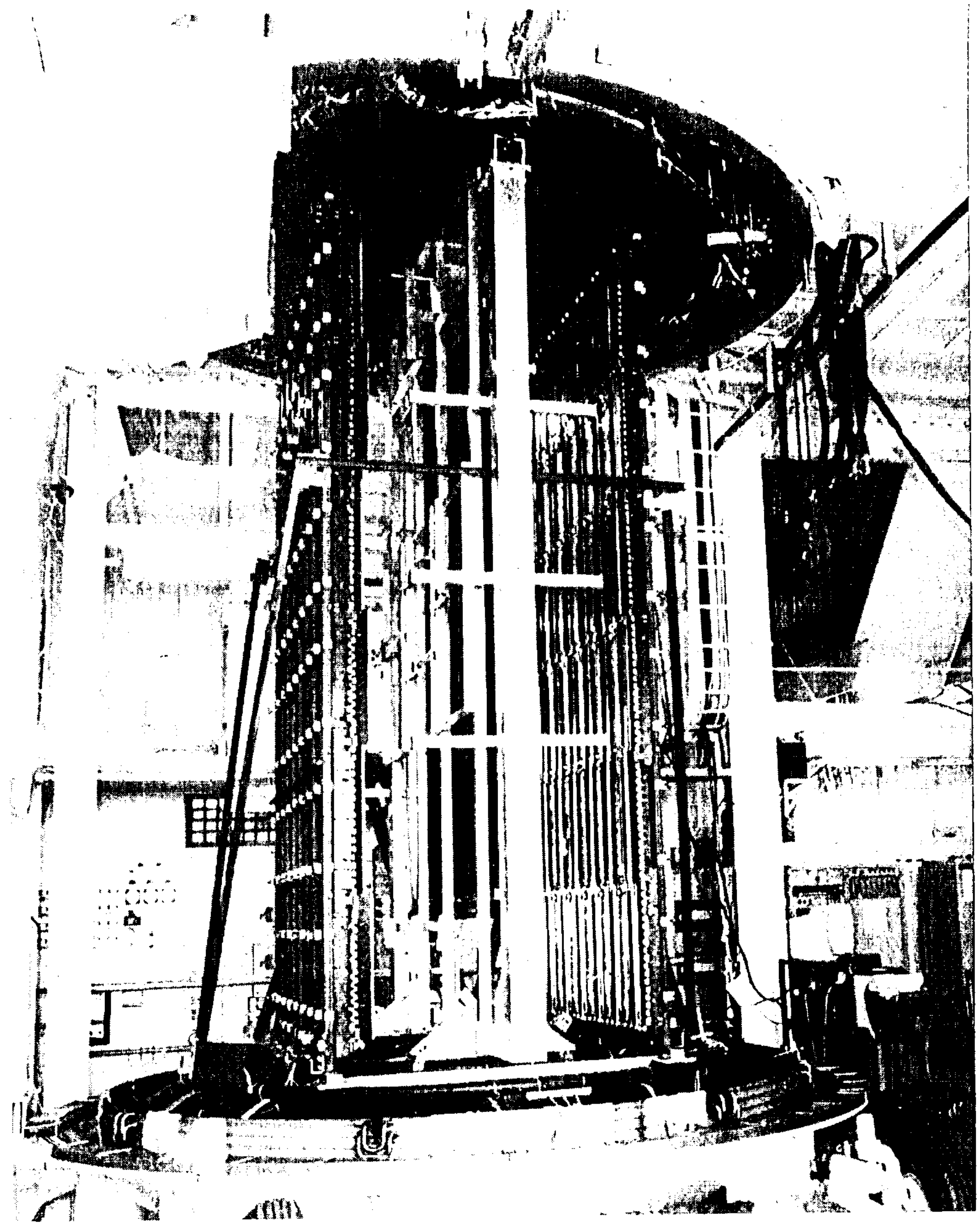

Figure 3. The test chamber.

6. THE LAMP ARRAYS

The two lamp arrays consisted of 72, lamps each, supported on two unistrut frames that support vertically oriented lamp holder modules (Figure 4). The vertical stacks of lamps are movable to allow tailoring of the flux density of the array. The. lamp reflectors at the edges have an additional adjustable "blinder" reflector to control falloff. The modularity of the vertical lamp rows, the capability of the lamp modules to change, the reflector area, and the adjustability of lamp filament to reflector height for flux density control give the thermal engineer custom tailoring and easy tuning of the thermal distribution to the panel. The lamp circuitry is distributed for zone heating and picture frame edge effects, and each of the outer lamps is equipped with adjustable blinder-like reflectors for edge illumination control. The lamps used in the array were typical quartz envelope lamps 1 cm in diameter with a tungsten filament approximately 64 cm long. The lamps can produce 40 W/cm but are derated 100 percent for safety and long operating life.

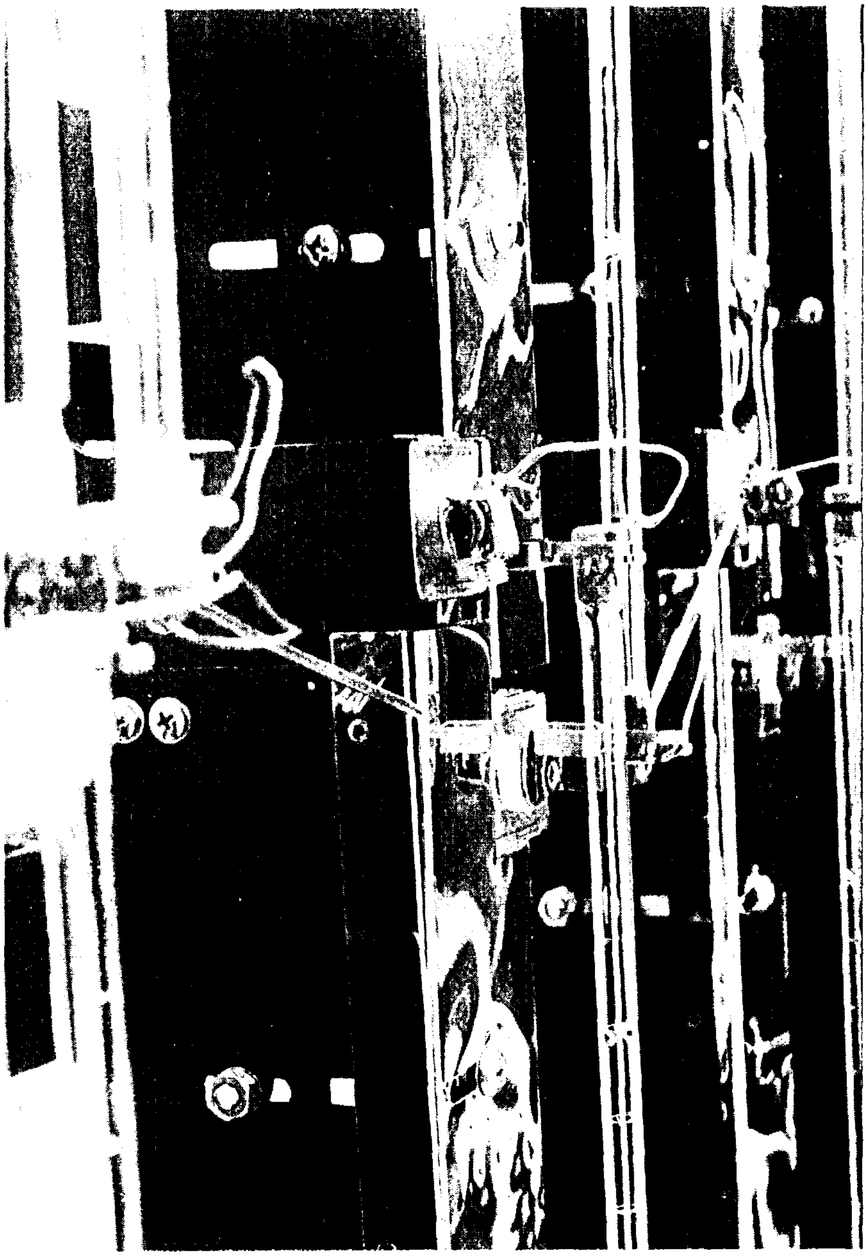

Figure 4. The vertically oriented lamp holder modules.

7. THE POWER CONTROL SYSTEM

The new control system consists of PC software programs, advanced silicon controlled rectifier (SCR) power controllers, and sensing devices such thermocouples, platinum resistance thermometers, and calorimeters, which arc used in the averaging network with 24 thermocouples on the panel front surface and 12 thermocouples distributed on the back side for safety alarms and power shutoff. One temperature sensor was selected for the closed-loop control system. The system (Figure 5) is based on flexibility and modularity to enable it to work with all kinds of environmental-testing support. The TOPEX solar panel test required four modules using 350 kW to drive 144 lamps. The start-up lamp filament resistance is very large and changes with temperature, so a special start-up programmed warm-up is used to overcome 7Ω or more when the filament is cold. The control system works in a totally automated or manual mode. The SCR power supplies have an optical link for phase balancing

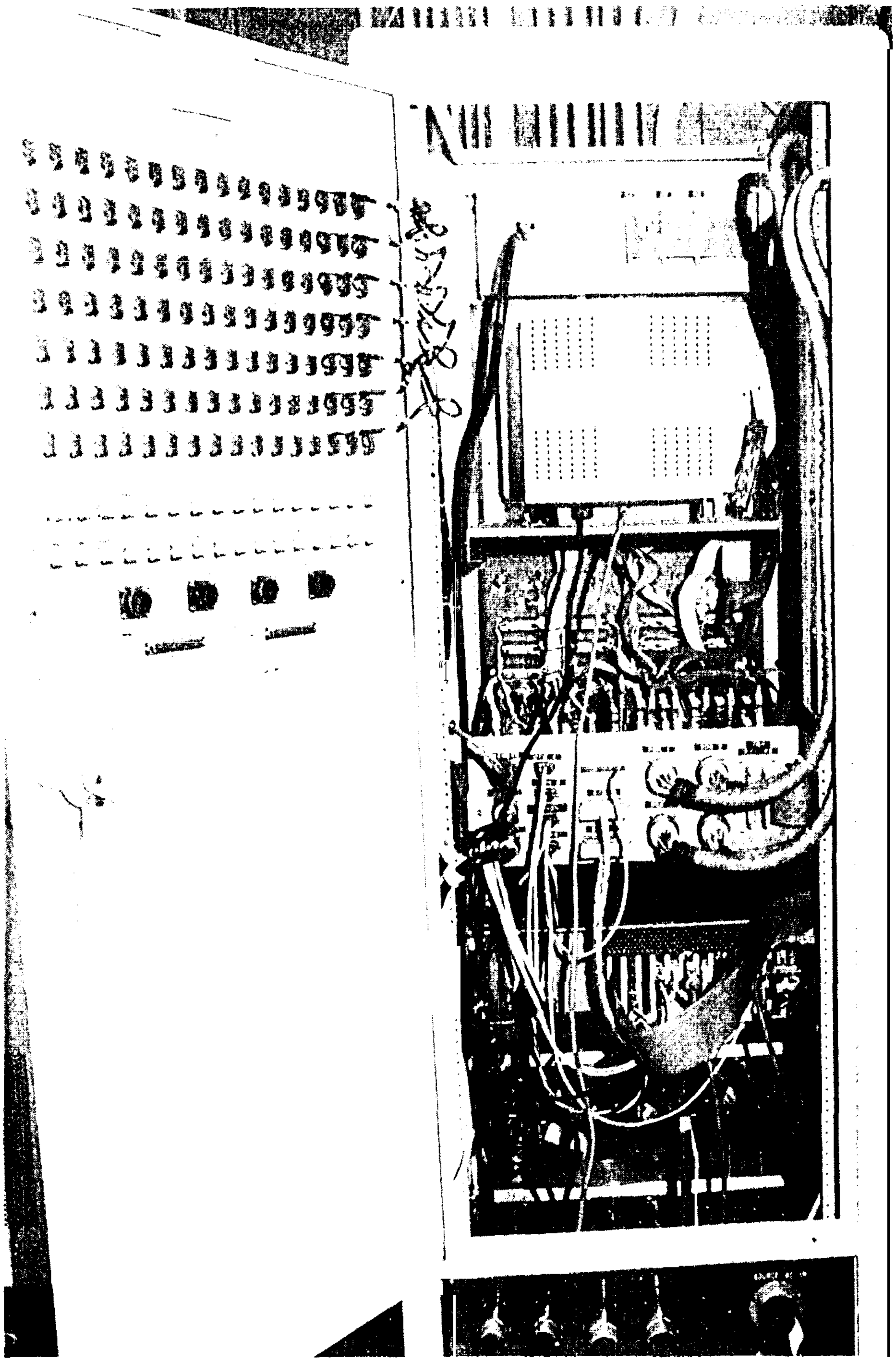

Figure 5. The power control system.

of incoming power. The SCR's are configured in electronic racks to supply 120 V AC (1-phase power), **208** V AC (2-phase power), and 480 V AC (3-phase power). The power modules can be staged for various lamp circuit loads. The distribution racks are self-contained with circuit breakers, SCR's, fuses, and analog status indicators. One rack serves as the host for all manual or closed-loop operation, which is monitored with a PC-based controller (Figure 6).

The system is easily configured through software for real-time changes to the testing program. The temperature devices used for control are J-type and K-type thermocouples (four-wire), resistance-temperature sensors, and calorimeters. The control system has a number of safety features that are used to monitor solar panel temperature through strings of sensors; these

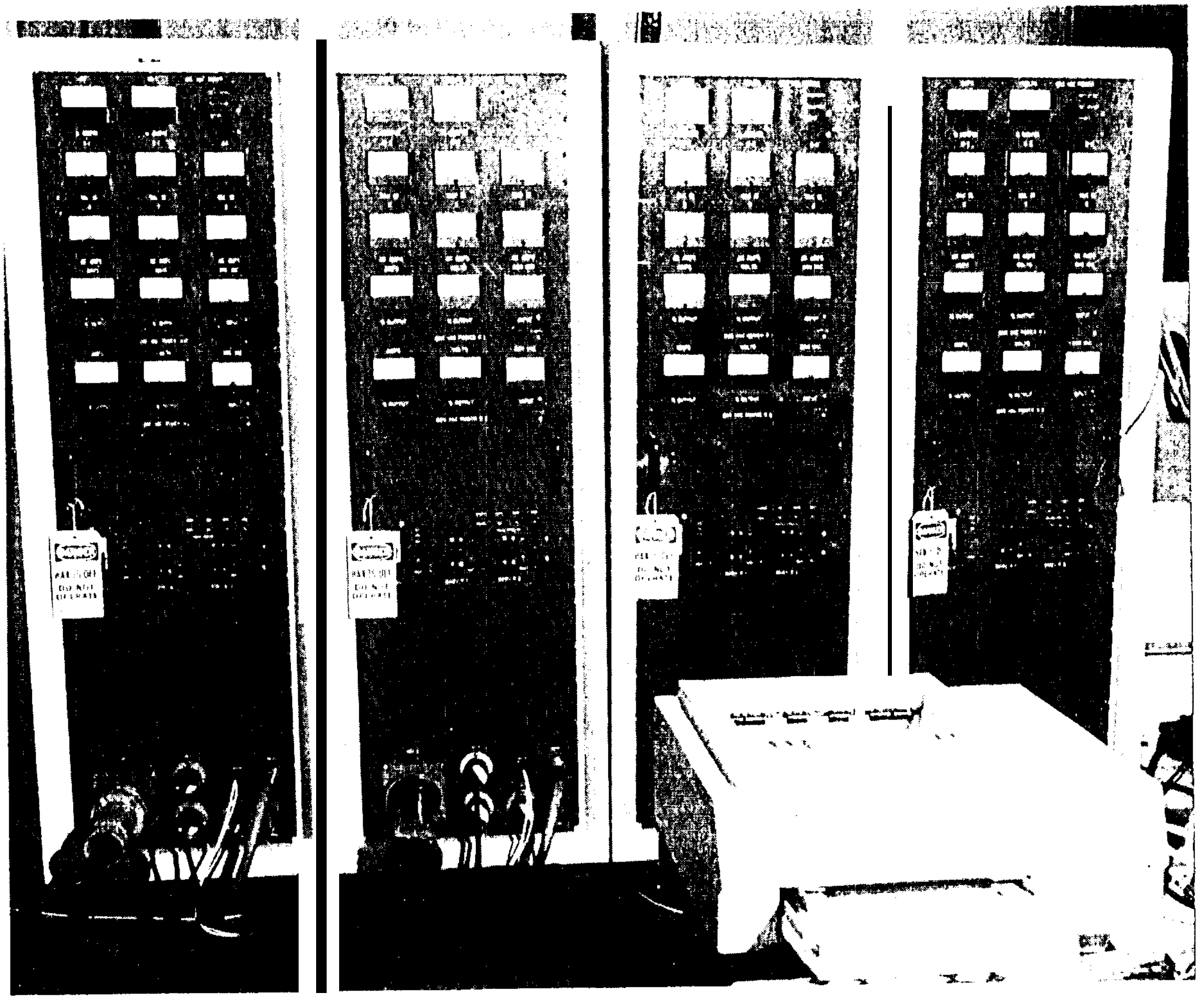

Figure 6. Four distribution racks.

features compare averages to preset alarm values and take proper action to announce warnings, lower power levels, or kill power to the lamps. The unit has the capacity for 12 control loops, each capable of controlling its own set program or time line. The power is ramped in each loop to meet specific targets or to carry out transitions in the test program. The software was written in QuickBASIC and C++ (Figure 7).

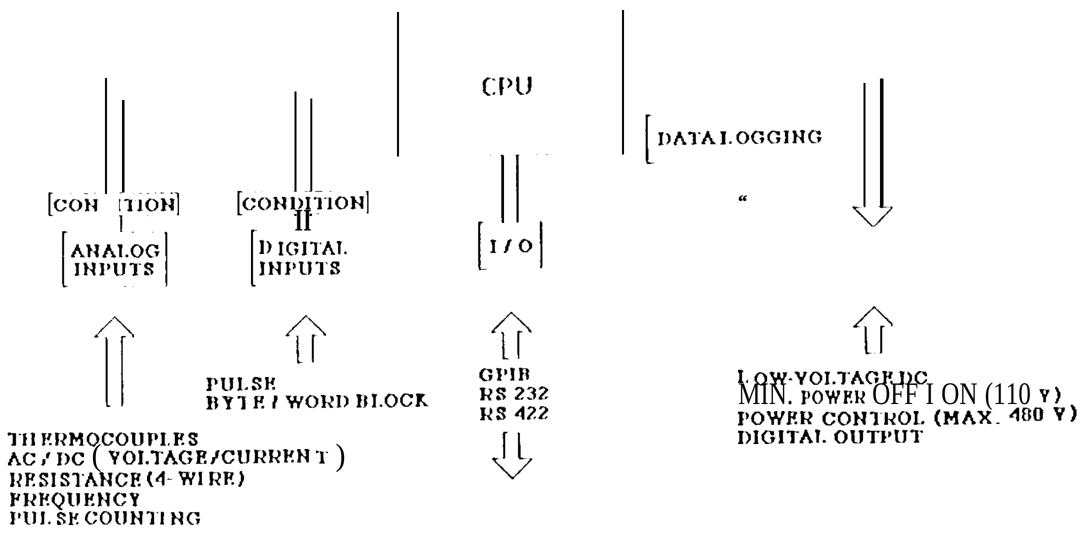

Figure 7. A diagram of the power control system's software.

8. THE FLUX VERIFICATION TECHNIQUE

The verification technique developed at JPL for IR mapping of the flux induced by IR lamp sources was first used for the MLS in 1989. The flux falling on the test panels is simulated by substituting a framed, thin, carbon-filled kapton membrane for the test panels (Figure 8). The mapping is done in a large, high bay to accommodate the convective air current that results from the lamps heating the air. The **lamp** array is hung horizontally, and the framed kapton membrane is supported below it at the distance of the lamp array from a solar panel. An imaging infrared camera/recorder using a gold-front-surface mirror at 45 degrees to increase view angle is moved about on a dolly on the floor below and looks up at the flux pattern radiating from the kapton/carbon. The mapping data are consistent with the modeling that was used to configure the lamp array. Small adjustments can be made to change reflective areas or spacing between sources to balance the. distribution. The control system blends and balances the lamp power to achieve the final flux level desired. The typical thermal cycling performance of the IR lamp system for the TOPEX solar panels is shown in Figure 9.

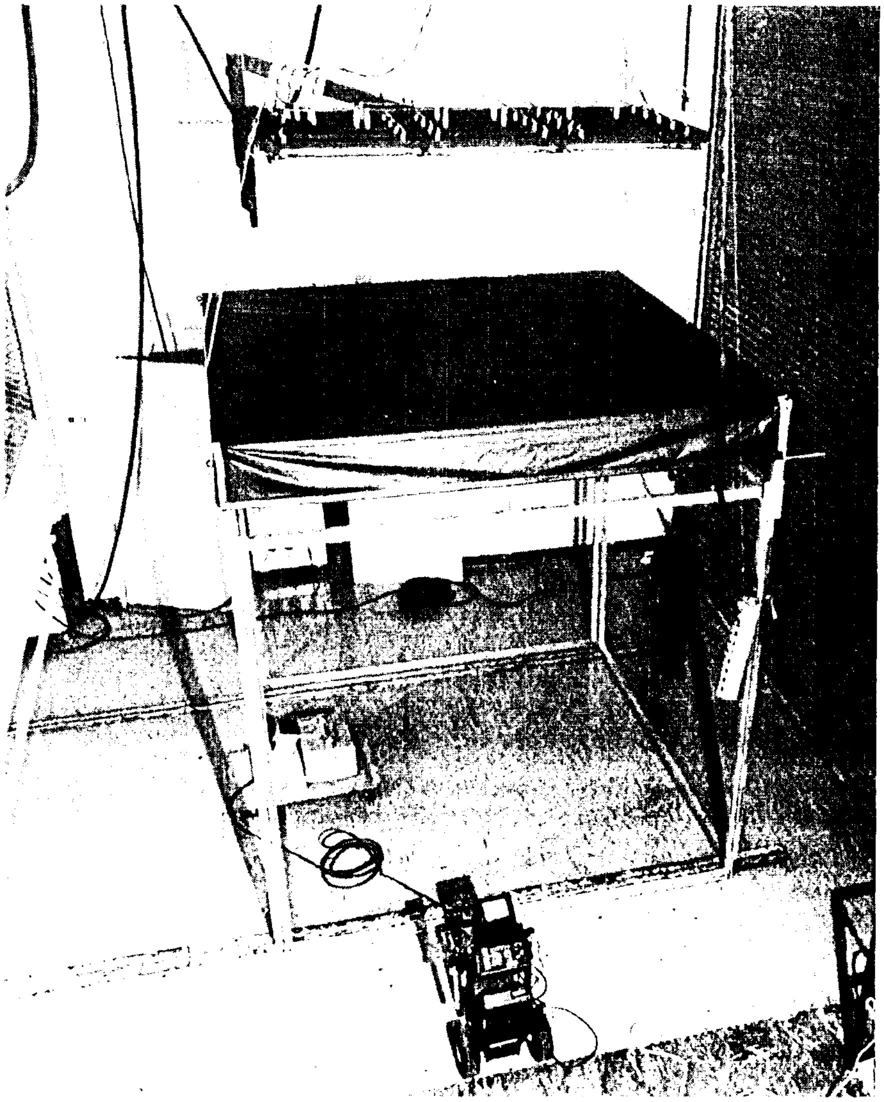

Figure 8. Photograph of the thermal mapping hardware and the test membrane.

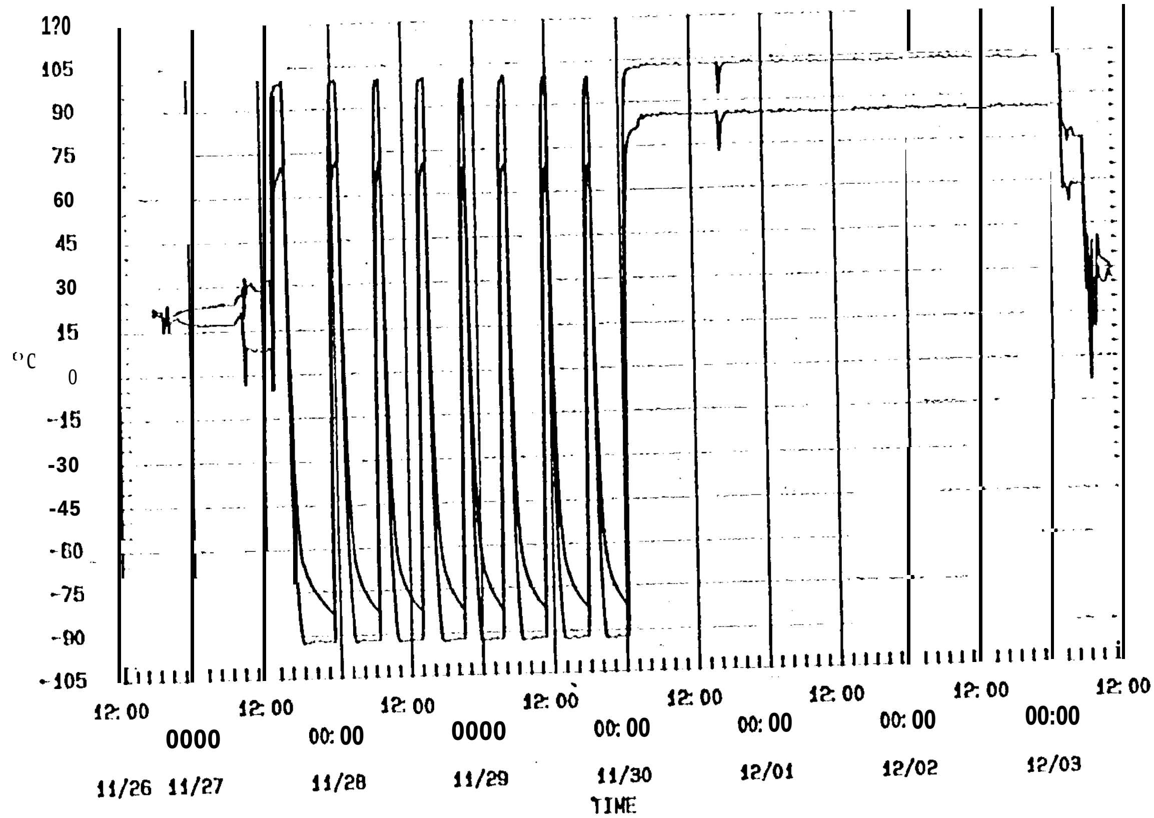

Figure 9. The typical thermal cycling performance of the system for the TOPEX solar panels.

9. CONCLUSION

The flight-testing program for the TOPEX project has brought about innovations resulting in a large-scale, modular, IR environmental simulation system. The system has proven to have great flexibility and to be easy to reconfigure for large and small testing applications. It is now a sustaining part of the environmental testing facility and is cost effective in its capability to drive the test hardware through real-time cycles with precision temperature-profile control. This capability successfully reduces testing time. The system's safety for flight hardware testing has been proven in performance. The system capabilities have led to new testing parameters not previously considered because of safety and cost.

10. ACKNOWLEDGMENTS

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12. AUTHOR BIOGRAPHY

E. W. Noller has been involved with space hardware design and the development of special space simulation techniques for flight projects at the Jet Propulsion Laboratory. He designed shock tube devices for material studies in the early days of the space program and supported designs for other composite-dominated space applications. He has designed thermal vacuum simulator systems, starting with the Viking spacecraft solar panel testing, and supported designs for many other composite-dominated space. applications. He has been responsible for research in vacuum deposition of thin and thick films on large composite reflectors, antenna elements, and metal optics.