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Patrick S. Wu
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA

S.-C. Lee
Applied Sciences Laboratory, Inc.
Hacienda Heights, CA

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THERMAL DESIGN AND TEST VERIFICATION OF THE GALAXY EVOLUTION EXPLORER

Patrick S. Wu†
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA

Siu-Chun Lee*
Applied Sciences Laboratory, Inc.
Hacienda Heights, CA

ABSTRACT

This paper describes the thermal control design of GALEX, an ultraviolet telescope that investigates the UV properties of local galaxies, history of star formation, and global causes of star formation and evolution. The telescope consists of a primary mirror for collecting light into the second mirror, which in turn focuses light onto the detectors located inside a focal plane assembly. In addition to the typical thermal requirements for hardware within the instruments, the spatial temperature variation within the primary and secondary mirrors must be kept within 1°C. The GALEX thermal design utilizes appropriate surface coatings, multi-layer insulation blanket, radiators, heaters, and thermostats. A detailed analytical model that accurately represented the GALEX mechanical configuration was constructed by utilizing SINDA/3D. Radiation exchange factors and environmental absorbed fluxes were calculated by using TSS. The thermal design analyses considered extreme, but realistic environmental parameters in conjunction with flight mission parameters to predict the maximum and minimum temperatures for the optical components and all electronic equipment. A comprehensive GALEX thermal design was presented in 2000 AIAA Technical Paper (Reference 1). This paper focuses on the thermal balance test conducted in February 2001 at JPL to verify the thermal design of the GALEX instrument.

INTRODUCTION

Galaxy Evolution Explorer (GALEX) is a space-imaging telescope that investigates the ultraviolet (1350-3000 Å) properties of local galaxies and maps the history of star

† Senior Thermal Engineer

* Senior Member, President

formation. It is scheduled to launch on a 3-axis stabilized spacecraft on May 2003 by utilizing the Pegasus XL into a 690-km circular orbit with an orbit plane inclination of 28.5°. It is a 29-month mission, with the telescope performing all-sky survey and deep surveys at night. The range of thermal beta angles is expected to be ±52°. Figure 1 show s a sketch of this instrument. It consists of a primary mirror and a secondary mirror plus outer barrel baffle, detectors and electronics boxes.

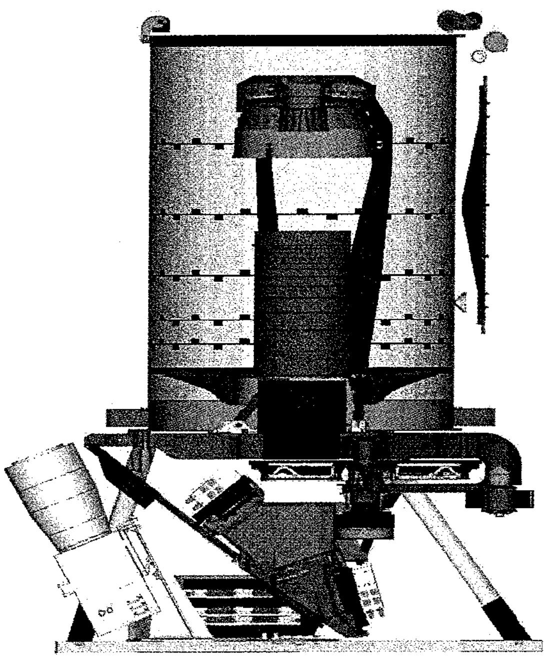

Figure 1. Galex Instrument

The thermal control employs are conventional approach using multi-layer insulation (MLI) and appropriate thermal control coatings; thermal shields with heaters for M1 and M2. Also, for the instrument deck there are dedicated white painted radiators for DPU and FEE electronic boxes. This instrument employs three kinds of heaters mainly operational, survival and decontamination. The heaters' set points and power can be controlled to different values by DPU. Thermostats located on DPU chassis control survival heaters. In addition, there are 24 flight temperature sensors installed. The instrument configuration before thermal test is shown in Figure 2.

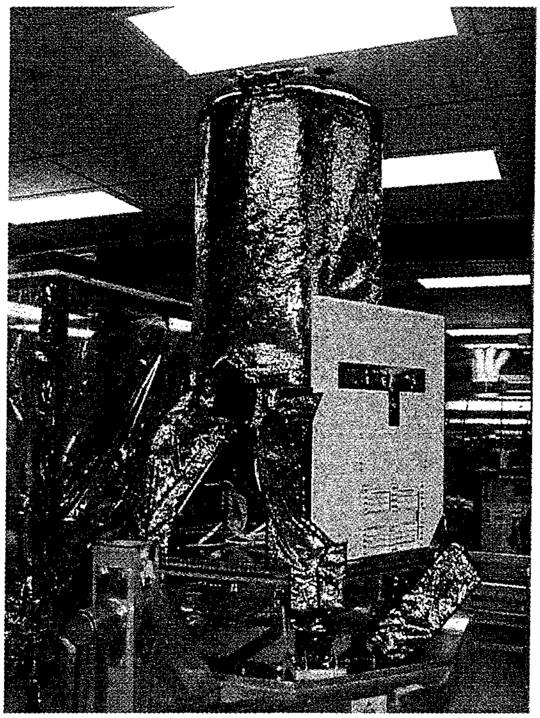

Figure 2. Galex Instrument Picture Before TV test

The GALEX thermal vacuum test consists of three major test phases: thermal balance, thermal cycling, and optical calibration. The thermal balance test phase includes testing at temperature levels that simulate the predicted temperatures that would be attained by the optics components and electronic equipment under the extreme hot and cold flight operating and non-operating conditions. Three cycles of thermal vacuum test simulating the predicted flight temperatures at the extreme hot operating and cold non-operating conditions then follow. Upon completion of the thermal cycling test, a different Hartmann screen is then installed for the performance of optical calibration test. The flight instrument will be maintained at temperature levels corresponding to the hot, cold, and nominal flight operating conditions as specified by the science team.

The articles for these tests are:

a) The flight instrument that includes the Telescope Assembly (TA), the outer baffle and its cover, the instrument deck that houses the Grism/Optical Wheel (GR/OW) assembly, the Back Focal Plane assembly, and the DPU, FEE and HVPS. It is mounted horizontally on a support fixture and fitted inside a 47.5"x120" vacuum chamber.
b) Directly opposite to the instrument inside the vacuum chamber is the Collimator that is also mounted horizontally. The Collimator refers to only the telescope that is supported on top of the telescope support plate (TSP) and excludes the outer barrel. The Collimator is needed for the calibration and optical performance characterization test phases.

The thermal balance test phases include steady state dwell of the flight instrument at various temperature levels that correspond to the extreme hot and cold operating modes, decontamination mode, and the extreme hot and cold non-operating modes. Both transient and steady state temperature data are collected during all the test phases, which are used to validate the thermal control design and for correlating the thermal math model. During the thermal balance tests at the extreme hot and cold operating conditions, the science team will be conducting optical performance verification tests. The operational heaters on the M2 hub and shield are to change the focus of the telescope. M2 will be varied from –15 to +25C at both the hot and cold operating conditions.

The thermal cycling test at the hot operating and cold survival temperature levels provides environmental stress screening to detect defects in material, process, and workmanship that can only be detected in vacuum conditions. Thermal cycling in vacuum allows screening for defects that can only be detected in a vacuum environment.

The thermal balance and thermal cycling tests constitute all of the tests that are required for the verification of the GALEX thermal design. Optical performance tests are performed concurrently by the science team during the thermal balance tests at the operating modes. Upon completion of the thermal cycling tests, the flight instrument will be returned to ambient condition carefully in order to prevent contamination of the optics. The test chamber will be opened and a different Hartmann screen will be installed for the calibration test phase. Calibration will be performed with GALEX maintained at the hot, cold, and nominal flight operating conditions.

Test Chamber

The GALEX thermal vacuum test will be conducted by utilizing a 10' (length) by 47.5" (diameter) chamber with doors on both ends. This chamber resides inside a class 10000 clean room within a JPL building. A cylindrical enclosure consisting of 6-ft long temperature-controlled shrouds is installed on one side (designated as the left compartment). The temperature-controlled shrouds are comprised of two axial sections and cylindrical disks on both ends. The flight test article is located inside the temperature-controlled shrouds, whereas the Collimator is positioned inside the right compartment and is exposed to the chamber walls at room temperature.

Figure 3 shows a schematic diagram of the chamber shroud system. Each axial section of the temperature-controlled shrouds contains four circular quarter panels. The panels that comprised of the axial section closest to the chamber door on the left compartment are designated as the West shrouds, and panels on the other axial section are referred to as the East shrouds. The disk panel adjacent to the East shrouds is a Hartmann screen that is covered with a 15-layer MLI blanket on the side facing the Collimator. A temperature-controlled disk panel adjacent to the West shrouds provides the simulation of the spacecraft interface.

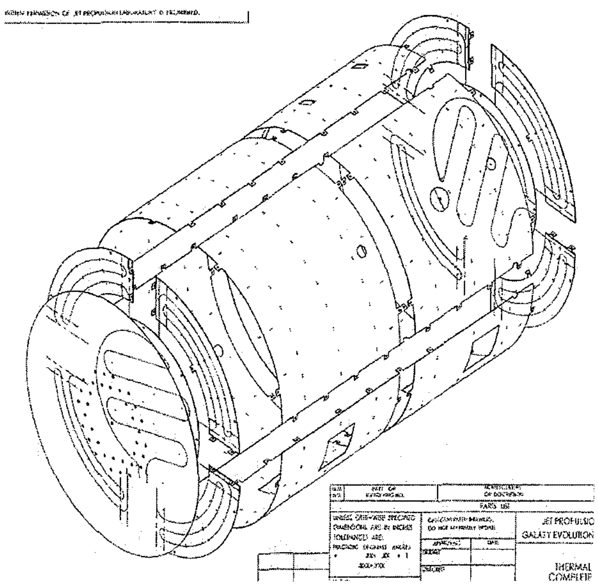

Figure 3. Test Chamber Sketch

GN2 flowing through the coolant lines that are brazed onto the panels cools the temperature-controlled shrouds. Three temperature controllers are used to regulate the inlet GN2 temperature. Figure 4 depicts the temperature control of the chamber shrouds. One controller controls the temperature of GN2 supplied to the Hartmann screen. Two other temperature controllers independently regulate the temperatures of GN2 supply to two manifolds, with one manifold supplying GN2 to the East shrouds and the other to the West shrouds. The simulated spacecraft interface plate will be controlled at -10 and +40C. Kapton film heaters are bonded to all the shroud panels, which are used to raise the sub-cooled shrouds to the desired temperature levels

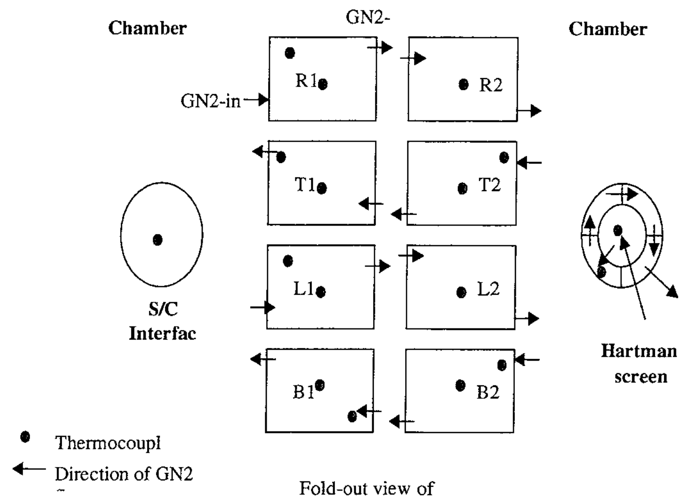

Figure 4. Schematic diagram showing the temperature control of the chamber shroud.

Table 1 gives a summary of the number and size of heaters bonded to the panels.

Table 1. Summary of thermal vacuum chamber shroud heaters.

Chamber shroud	Number of heater	Power/ Heater	Heater Size
Top 1	8	20.0 W	3"x20"
Top 2	8	20.0 W	3"x6"
Right 1	8	20.0 W	3"x20"
Right 2	7	20.0 W	3"x6"
Bottom 1	8	20.0 W	3"x6"
Bottom 2	8	20.0 W	3"x6"
Left 1	8	20.0 W	3"x20"
Left 2	7	20.0 W	3"x20"
Hartmann screen	2	50.0 W	2"x6"
S/C Interface plate	5	40.0 W	3"x10"

Test Article

The test article is the GALEX instrument in a near flight-like configuration. It consists of the Telescope Assembly, the telescope cover in the deployed position, the flight all equipment inside the instrument compartment, and the DPU and FEE radiators. All flight thermistors and heaters, as well as MLI blankets on the telescope barrel, MLI on the channels of the M2 support struts, MLI inside the M2 cap, and the MLI tent that encloses the instrument compartment will all be installed. However, the star tracker that is provided by the spacecraft contractor, Orbital Sciences Corp., will not be present for the test.

The test article is mounted in a horizontal position cantilevered off a support truss. The instrument deck is secured to the truss at six places utilizing keenserts, which is also attached to the simulated spacecraft interface plate. Figure 5 shows a photograph of the test article. Figure 6 shows a schematic diagram of GALEX and the Collimator inside the test chamber. The Collimator is located on the right side of the chamber and is exposed to the chamber walls that are at room temperature.

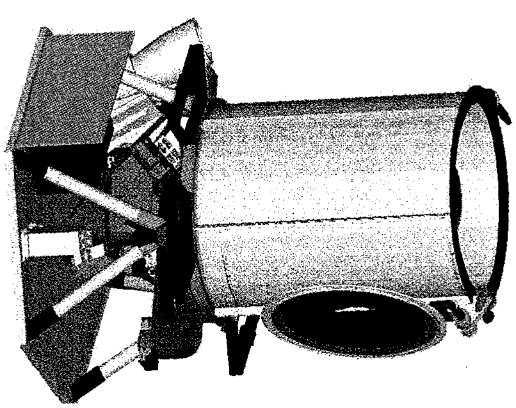

Figure 5 Photograph of the GALEX instrument in TVT configuration.

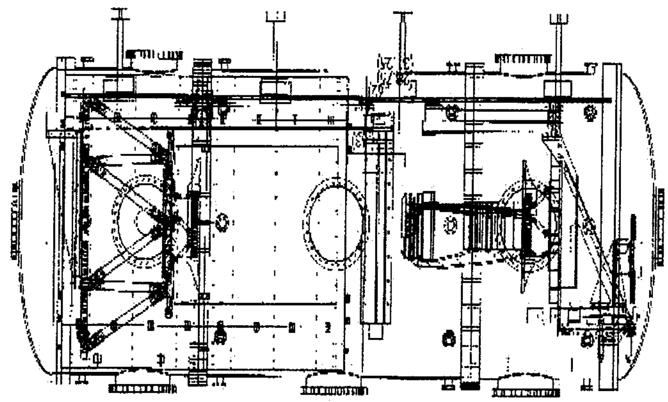

Figure 6. Schematic diagram of test article and Collimator inside the test chamber.

All of the flight heaters and thermistors are installed on the GALEX instrument. Table 2 lists all the operational and replacement heaters that are applied on the flight instrument. Both the operational and decontamination heaters are controlled by the DPU. The temperature set-points and input power of these heaters can be varied by modifying the software input into the DPU. Thermostats bonded on the DPU and FEE chassis and radiators control survival heaters. While most of the kapton film heaters are for either operational, decontamination or survival and thus have only one pair of lead wires, the film heaters on the GR/OW baffle and disk consist of two separate heaters built-into the kapton film. Two pairs of lead wires emanate from each of these heaters, with one pair of lead wires for the operational heater and the other for the survival heater.

In the survival mode, heaters are needed to keep the optics and electronic equipment above their respective non-operating allowable flight temperature (AFT) limits. Survival heaters are bonded on the M1 and M2 shields, the GR/OW cylindrical baffle and disk, the NUV and FUV detectors, as well

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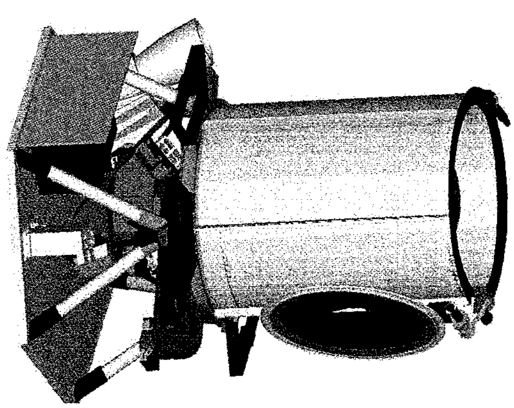

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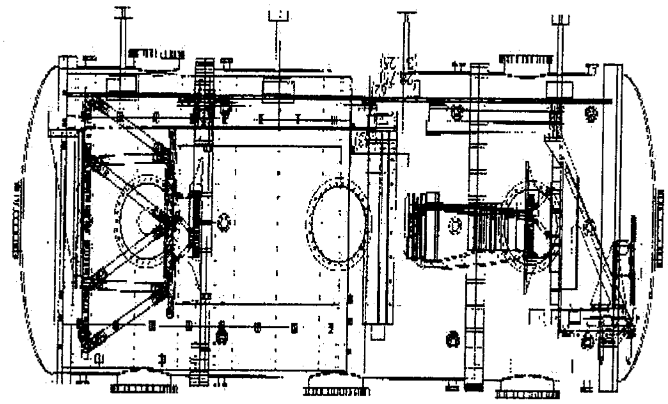

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In the survival mode, heaters are needed to keep the optics and electronic equipment above their respective non-operating allowable flight temperature (AFT) limits. Survival heaters are bonded on the M1 and M2 shields, the GR/OW cylindrical baffle and disk, the NUV and FUV detectors, as well as the DPU, FEE, and HVPS. Thermostats bonded on the DPU and FEE chassis and the respective radiators activate these heaters. Table 3 lists the thermostats and the control authority of each set of thermostats. The thermostats on the DPU chassis control the circuit that includes the survival heaters on the DPU, GR/OW baffle and disk, FUV and NUV detectors, and the HVPS. The thermostats on the DPU radiator control the survival heaters on the M1 and M2 shields. Survival heaters on the FEE are divided into two circuits, with one set controlled by thermostats on the FEE chassis and the other set by thermostats on the FEE radiator. Figures 6-8 delineate the survival heater circuits and the thermostats that control the survival heaters.

Heater ID	Location	Mode	Power @26V
H1-H6	M1 hub	Op	6.03
H7,H8	M1 Shield	Op	8.31
H9, H10	M1 Shield	Survival	26.33
H11, H12	M1 Shield	Decon	81.13
H13-H18	M2 Hub	Decon/Op	3.56
H19-H21	M2 Shield	Decon/Op	1.89
H22-H25	M2 Shield	Decon/Op	8
H26, H27	M2 Shield	Survival	1.89
H28	GR/OW Cyl Baffle	Op	5.96
H29	GR/OW Disk Heater	Op	0.83
H28a	GR/OW Cyl Baffle	Survival	2.09
H29a	GR/OW Disk Heater	Survival	0.42
H30, H31	DPU	Survival	23.76
H32, H33	FEE	Survival	23.15
H34-H37	FEE	Survival	40
H38, H39	HVPS	Survival	2.09
H40, H41	NUV Detector	Survival	5.32
H42, H43	FUV Detector	Survival	5.32

Table 2. Operational and survival heaters

T/S ID#	Average Opening Temp, C	Average Closing Temp, C	Location	Controls Survival eaters on:
1	1.3	-6.5	Primary, DPU Chassis	DPU, HVPS, NUV, FUV, GR/OW baffle, GR/OW disk
2	-5.9	-11.9	Secondary, DPU Chassis	DPU, HVPS, NUV, FUV, GR/OW baffle, GR/OW disk
3	8.9	-0.3	Primary, DPU Radiator	M1 and M2
4	0.9	-6.3	Secondary, DPU Radiator	M1 and M2
5	1.3	-6.2	Primary, FEE Radiator	Top and Bottom of FEE Chassis
6	-3.7	-11.2	Secondary, FEE Radiator	Top and Bottom of FEE Chassis
7	1.4	-5.9	Primary, FEE Chassis	Top, Bottom & sides of FEE Chassis
8	-4.9	-10.6	Primary, FEE Chassis	Top, Bottom & sides of FEE Chassis

Table 3. Summary of thermostats on the flight instrument.

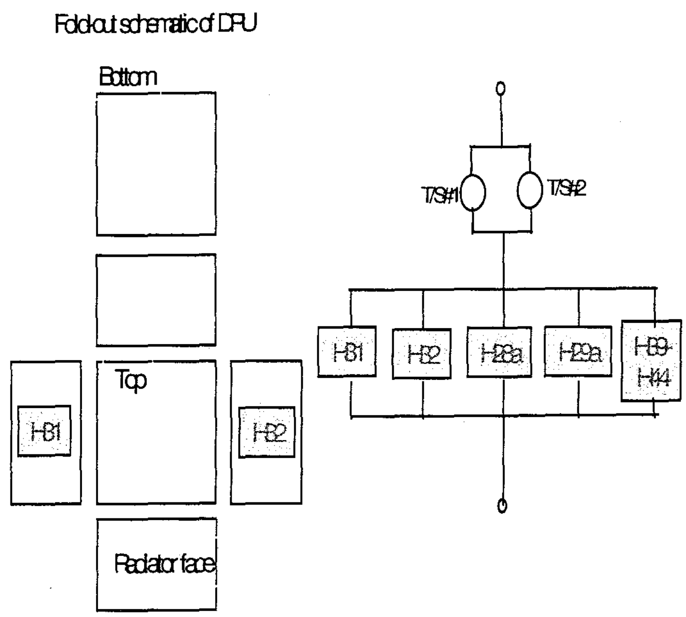


Figure 6. Survival heaters activated by thermostats on DPU chassis.

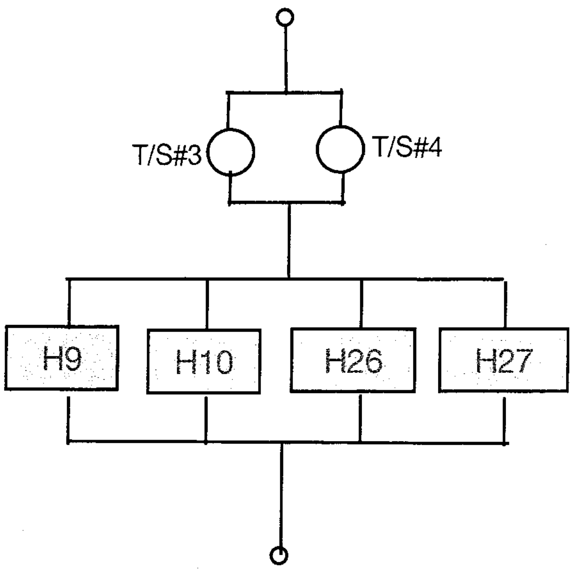
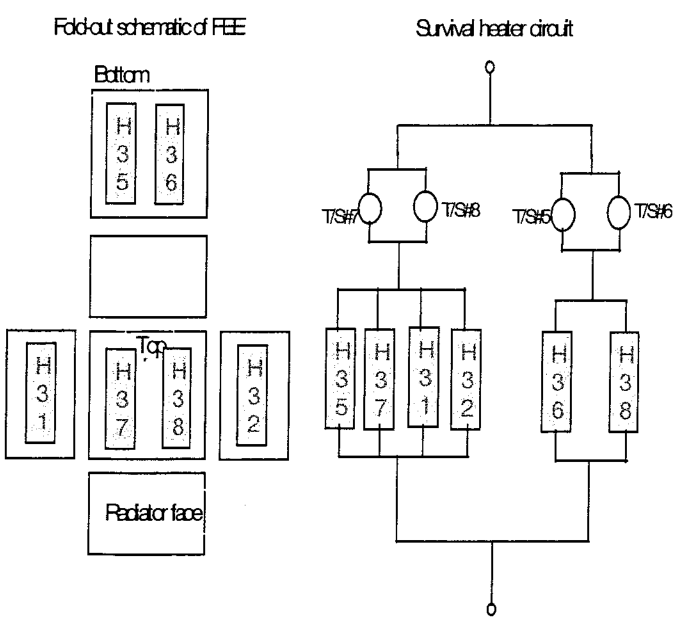


Figure 7. Survival heaters and thermostats on the DPU radiator.



.Figure 8. Survival heaters and thermostats on the FEE.

THERMAL BALANCE TEMPERATURE PROFILE

The thermal balance test consists of five test phases that simulate the predicted temperatures that would be attained by the optics components and electronic equipment under the extreme hot and cold flight operating and non-operating conditions. While the instrument is turned on or turned off depending on the test phase, the survival heater circuit must be enabled at all times. Figure 8 shows the sequence of the test phases. A preliminary estimate of the test duration is about 3 weeks as indicated in the figure.

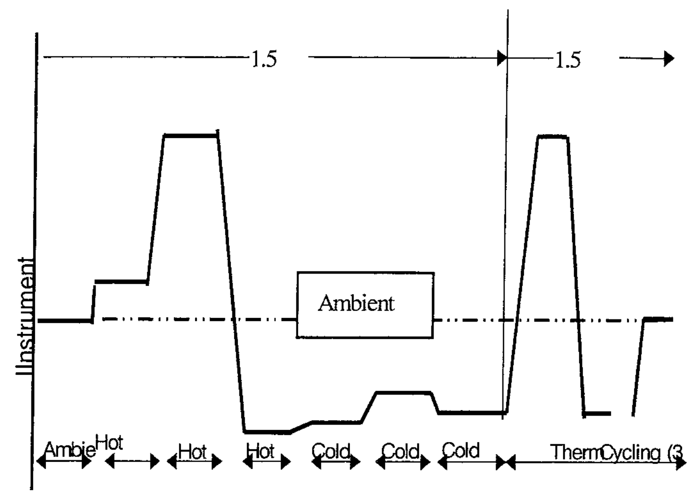


Figure 9. Thermal balance Test Temperature Profile

THERMAL TEST RESULTS AND DATA CORRELATION

The test data from the hot and cold balance conditions have been processed and compared with the thermal model temperature predictions. The pre-test temperatures are within 5C of measured values during all test phases. The predicted and actual heater power usage agreed to within 10%. It is concluded that the thermal test data validated the instrument thermal model. Test correlation data for both the hot and cold balance conditions are shown in Tables 4 and 5.

Table 4. Hot Balance Test Results

Location	Test Result Average Temp. C	Model Prediction Average Temp. C	Temperature Difference, C
Secondary Mirror Hub	16.4	13.5	2.9
Secondary Mirror Shield	26.5	23.5	3
Secondatu Mirror	16.6	14.4	2.2
Light Cup	0.4	0.5	-0.1
Struts	-8.7	-16.7	8
Barrel	-3.3	-8.8	5.5
Primary Mirror Hub	-3	-9.1	6.1
Primary Mirror	-1.3	-7.3	6
Primary Miror Shield	-0.6	-6.4	5.8
TSP	2.8	1.3	1.5
Contamination Shield	2.2	-3.1	5.3
BFA Struts	11.6	8.9	2.7
BFA Housing	20	15.8	4.2
NUV Detector	23.2	17	6.2
FUV Detector	18.5	15.9	2.6
High Voltage Power Supply	23.4	26.4	-3
Date Proccessing Unit	18.4	14.8	3.6
Front End Electronics Box	20	21.8	-1.8
Instrument Deck	21.6	20	1.6
WTA	-40.2	-36.4	-3.8

Table 5. Cold Balance Test Results

Location	Test Result Average Temp. C	Model Prediction Average Temp. C	Temperature Difference, C
Secondary Mirror Hub	18.1	17.8	0.3
Secondary Mirror Shield	29.5	29.6	-0.1
Secondatu Mirror	18.6	18.9	-0.3
Light Cup	0.7	3	-2.3
Struts	-8.3	-15.4	7.1
Barrel	3.2	-1.4	4.6
Primary Mirror Hub	5.2	4.1	1.1
Primary Mirror	19.5	24.5	-5
Primary Miror Shield	31.4	33.9	-2.5
TSP	6.4	6.7	-0.3
Contamination Shield	7.3	4.5	2.8
BFA Struts	8.2	7.9	0.3
BFA Housing	16.4	14.4	2
NUV Detector	21.2	15.8	5.4
FUV Detector	21.2	15.8	5.4
High Voltage Power Supply	16.2	17.6	-1.4
Date Proccessing Unit	9.6	2.4	7.2
Front End Electronics Box	13.3	10.5	2.8
Instrument Deck	4.5	7.2	-2.7
WTA	-94.2	-96.6	2.4

CONCLUSION

A thermal control design that meets both temperature and heater power requirements for all operating and non-operating modes has been developed for the GALEX instrument. The thermal design was developed based on consideration of extreme environments and orbit attitudes consistent with mission constraints. A detailed thermal model of GALEX was developed for performing design trade studies. Extensive thermal analyses were performed to develop specifications for the surface finishes, MLI, and radiators, thermostats, and heaters. The thermal design utilizes operational and survival heaters for the optical and electronic equipment. Survival heaters are needed by all electronic equipment in the survival mode. Three sets of thermostats are used to control the survival heaters. Each set consists of two thermostats wired in parallel for added reliability. The GALEX thermal design was validated by the thermal balance test conducted in February 2001. The instrument has been delivered and integrated with the Orbital satellite. GALEX is scheduled to launch in May, 2002.

ACKNOWLEDGEMENTS

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