

Lessons Learned from the Wide Field Camera 3 TV1 and TV2 Thermal Vacuum Test Campaigns

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ABSTRACT

The Wide Field Camera 3 (WFC3) instrument has undergone two complete thermal vacuum tests (TV1 and TV2), during which valuable lessons were learned regarding test configuration, test execution, model capabilities, and modeling practices. The very complex thermal design of WFC3 produced a number of challenging aspects to ground testing with numerous ThermoElectric Coolers and heat pipes, not all of which were functional. Lessons learned during TV1 resulted in significant upgrades to the model capabilities and a change in the test environment approach for TV2. These upgrades proved invaluable during TV2 when pre-test modeling assumptions proved to be false.

Each of the lessons learned relate to one of two following broad statements:

1. Ensure the design can be tested and that the effect of non-flight like conditions is well understood, particularly with respect to non passive devices (TECs, Heat Pipes, etc)
2. Ensure that the model is sufficiently detailed and is capable of predicting off-nominal behavior and the power dissipation of any thermal devices, especially TECs

This paper outlines a number of the lessons learned over these two test campaigns with respect to the thermal design, model, and test configuration and presents recommendations for future tests.

1. INTRODUCTION

Wide Field Camera 3 (WFC3) is an instrument to replace the Wide Field Planetary Camera II instrument (WF/PC-II) on the Hubble Space Telescope (HST). The instrument consists of two channels: UV/Visible (UVIS) and Infrared (IR). A pickoff mirror reflects the incoming light to a channel select mechanism, which then directs the light through either the UVIS path or the IR path to the corresponding detector unit. Both the UVIS and IR

detector subsystems utilize multi stage Thermo Electric Coolers (TECs) to directly cool the detectors to the required temperatures, as well as TECs that control the surrounding shields/housings to isolate the detectors from the rest of the instrument. The instrument has two main radiators, one to reject the majority of the electronics heat and one to reject the detector heat. Furthermore, some of the lower dissipating electronics boxes reject their heat directly to the internal components of HST.

Shortly after the Columbia accident, further servicing missions to support HST were cancelled after being deemed high risk. The WFC3 program had reached a level of maturity and had sufficient funding to complete a characterization TV test of the instrument, should any future HST missions be reinstated or if the instrument were to fly on another mission. This test campaign was deemed TV1 and provided the first opportunity to validate the thermal model against test behavior. The test provided many lessons learned both from test configuration as well as modeling/correlation standpoints and proved invaluable to the flight program currently underway^{1,2}. Eventually, the mission was re-instated and further updates to the design were made as a result of a more updated flight environment characterization. The TV2 test campaign provided the means to validate these design updates and qualify the instrument for flight.

2. WFC3 THERMAL DESIGN

WFC3 consists of two actively cooled detectors (UVIS and IR), housed inside of temperature controlled units. The detector units themselves are mounted inside the thermally controlled Optical Bench. The bench is structurally tied to the HST frame via low conductivity struts connected to three thermally controlled latch points. The bench itself is thermally controlled by the Cold Plate mounted below the bench, which is maintained at temperature by a combination of heaters and a Variable Conductance Heat Pipe (VCHP). The entire Optical Bench and Cold Plate subsystems are

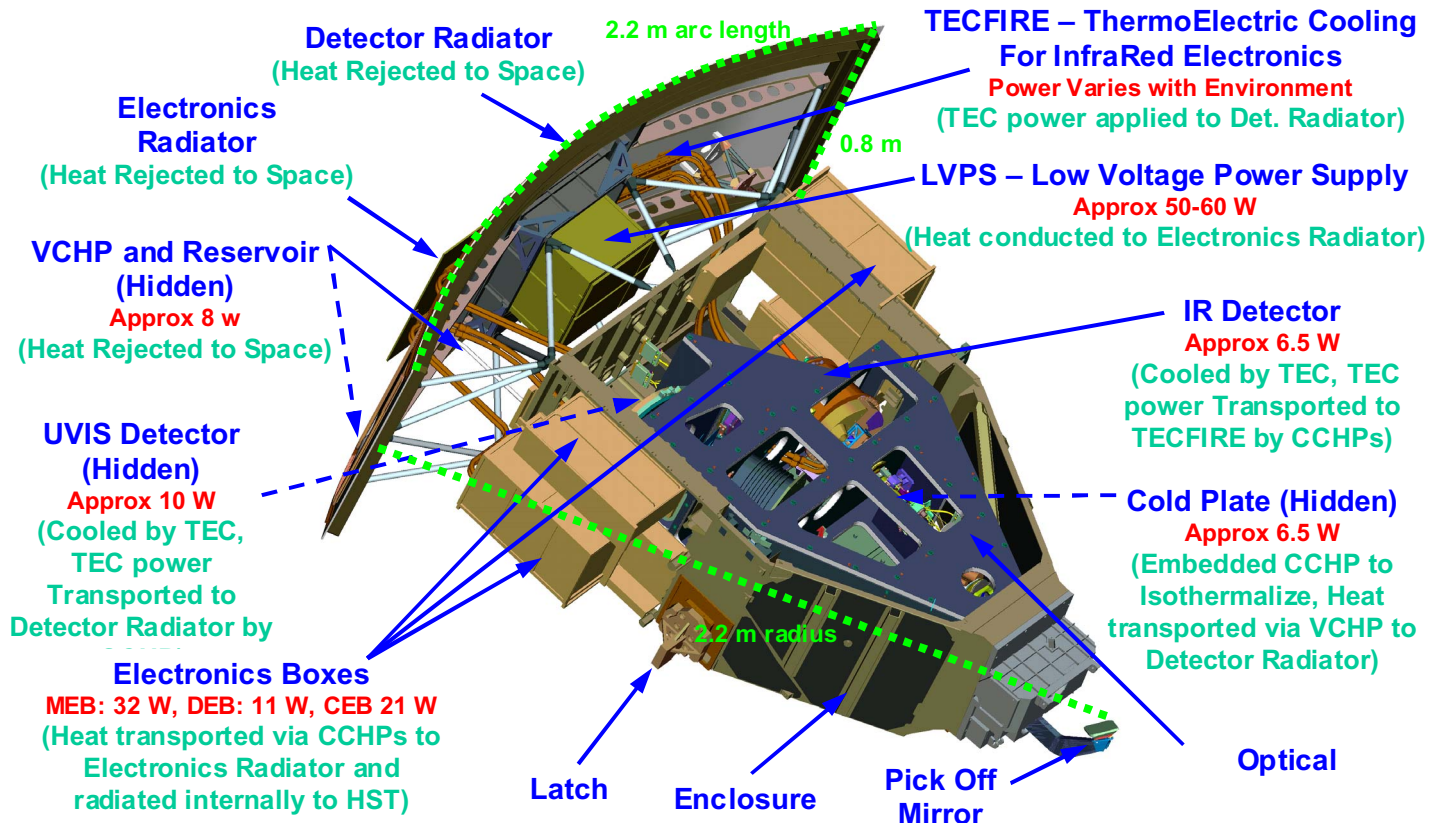


Figure 1 – Overview of WFC3 Thermal Design

radiatively isolated from the surroundings by multi-layer insulation (MLI). Furthermore, the surrounding MLI is enclosed in an exoskeleton panel configuration to which the external electronics boxes are mounted. Two radiators are employed to reject the majority of the power dissipation to space: the Detector Radiator and the Electronics Radiator. Figure 1 shows the general thermal design.

The Detector Radiator includes a network of six spreader heat pipes perpendicular to two header heat pipes (Upper and Lower) to help isothermalize the radiator and increase its efficiency. Figure 2 shows the detector radiator (with the electronics radiator removed) and the associated heat pipe network. A number of other heat pipes are used to move the heat from dissipation locations within the instrument to the dedicated radiators. Four major heat paths to the radiators exist: UVIS Detector, IR Detector, Optical Bench/Cold Plate, and Electronics Boxes.

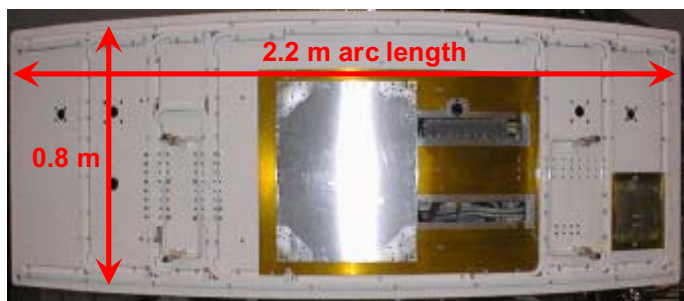


Figure 2 – Detector Radiator and Heat Pipe Network

The UVIS detector is a Charge Coupled Device (CCD) which is actively cooled by a 4-stage Thermo-Electric Cooler (TEC) to -83°C . Surrounding the UVIS detector is a radiative isolation shield which is cooled by four constant current, 2-stage TECs. The heat from these TECs is deposited on the UVIS detector baseplate, which is conductively coupled to the evaporator end of a Gas Charged Heat Pipe (GCHP). The condenser end of the GCHP is coupled directly to the Detector Radiator and rejects its heat to space. Figure 3 shows the UVIS detector thermal control system, as well as the thermal control system for the IR detector.

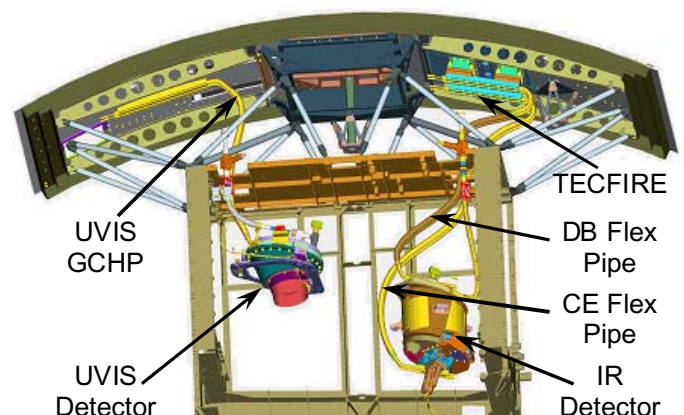


Figure 3 – Detector Radiator and Heat Pipe Network

Similarly, the IR detector consists of a Focal Plane Assembly (FPA) which is actively cooled by a 6-stage TEC to -128°C . The IR detector is housed inside a Cold Enclosure which provides a layer of isolation between the detector and the surrounding instrument surfaces. The heat from the 6-stage TEC is deposited on the detector assembly baseplate, which is conductively coupled to the evaporator end of a flexible heat pipe. Furthermore, the top of the Cold Enclosure is also coupled to the evaporator end of a second flexible heat pipe. The condenser temperatures of these two pipes are regulated by a subsystem called TECFIRE: Thermo-Electric Cooling For Infra-Red Electronics. TECFIRE consists of 3 assemblies, each of which contains six 1-stage TECs in parallel (2 for the detector baseplate: DB, and 1 for the Cold Enclosure: CE). TECFIRE provides a thermally stable interface to the condenser ends of the flex pipes and maintains -53°C for the DB and -45°C for the CE. The heat removed by the TECs, as well as the power generated by the TECs, is deposited directly on the Detector Radiator and rejected to space.

Both detectors reside inside the Optical Bench whose bulk temperature is maintained at 0°C nominally by the Cold Plate below the Optical Bench. The Cold Plate contains a constant conductance heat pipe (CCHP) embedded in the panel and a heater to help provide an isothermal, warm sink to regulate the Optical Bench temperature, as shown in Figure 4. Furthermore, the condenser end of the Cold Plate CCHP is coupled to the evaporator end of a VCHP, with the VCHP condenser coupled directly to the detector radiator. Therefore, both the VCHP and Cold Plate heaters are used to maintain the temperature of the Optical Bench.

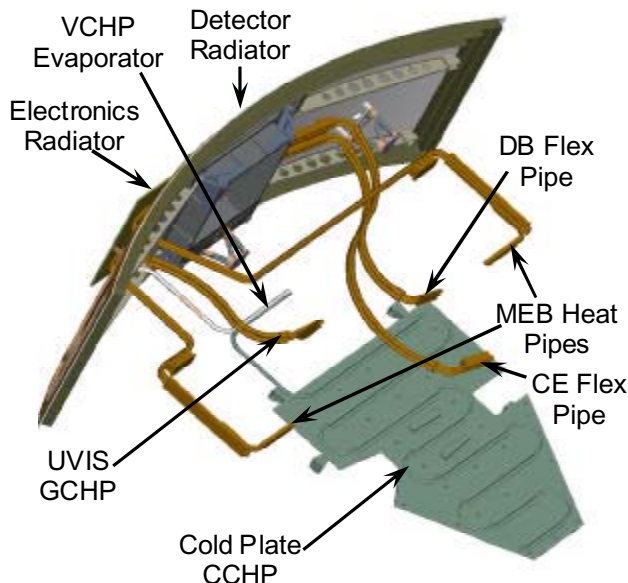


Figure 4 – WFC3 Thermal Control System Heat Pipes

Lastly, four major electronics boxes reject their heat to the Electronics Radiator or directly to the internal HST surfaces. The Main Electronic Boxes (MEB, nominally 32 W) are coupled to the Electronics Radiator via a CCHP and are coated with a low emissivity coating to minimize its radiative heat loss/gain from the internal

HST surfaces. The Low Voltage Power Supply (LVPS) is mounted directly to the back side of the Electronics Radiator, and rejects its heat to space through the Electronics Radiator. The Detector Electronics Box (DEB, nominally 11 W) and the CCD Electronic Box (CEB, nominally 21 W) are coated with high emissivity coatings and are intended to reject their heat directly to the internal HST components.

All of the heat pipes are nearly planar and may be ground tested if level, with the exception of the six vertical spreader heat pipes in the Detector Radiator.

3. TEST CONFIGURATIONS AND OVERVIEW

The TV1 test was conducted in late August through mid October in 2004 in the Space Environment Simulator TV chamber at Goddard Space Flight Center. The test setup is shown in Figure 5. The chamber shrouds were kept at ambient temperature and the instrument was surrounded by cryo-panels on each side (top, bottom, sides, and the radiators). Separate cryo-panels were maintained for the Electronics and Detector Radiators. Furthermore, two Ground Cooling Loops (GCLs) mounted to the Detector Radiator compensated for the lack of functioning spreader heat pipes, with one cooling loop used to control the TECFIRE side of the radiator, and the other used to control the UVIS side of the radiator. An optical stimulus system was used to characterize the science performance of the camera. Three balance points were achieved: Cold Operate, Hot Operate, and Cold Safe.

After the test, an initial correlation was performed using the values measured in test. Unfortunately, due to the cancellation of the mission, the thermal team who had supported much of the modeling and test efforts up to and through the test were no longer available. Once the servicing mission was re-instated, a new thermal team was assembled and the completion of the initial model correlation was performed. This entailed major updates to the prediction capability of the models, particularly in the areas of the TEC modeling. Valuable lessons were learned through this correlation effort.

Further investigation into the expected flight environments revealed a modeling error, resulting in the instrument predicting much colder than the intended design. Furthermore, project scientists were also interested in the possibility of operating the IR detector in a colder regime than planned. This led to a number of modifications to the design and operating parameters after the TV1 test, including: additional heaters on the Detector Radiator and lower setpoints for TECFIRE and the IR FPA. These design updates were validated during the TV2 test campaign, which took place between June and October of 2007. The test setup was identical to TV1, with the exception that the GCLs were connected for contingency purposes but were not intended to be used. The subsequent TV2 pre-test analysis, test campaign, and post-test correlation provided additional lessons learned.

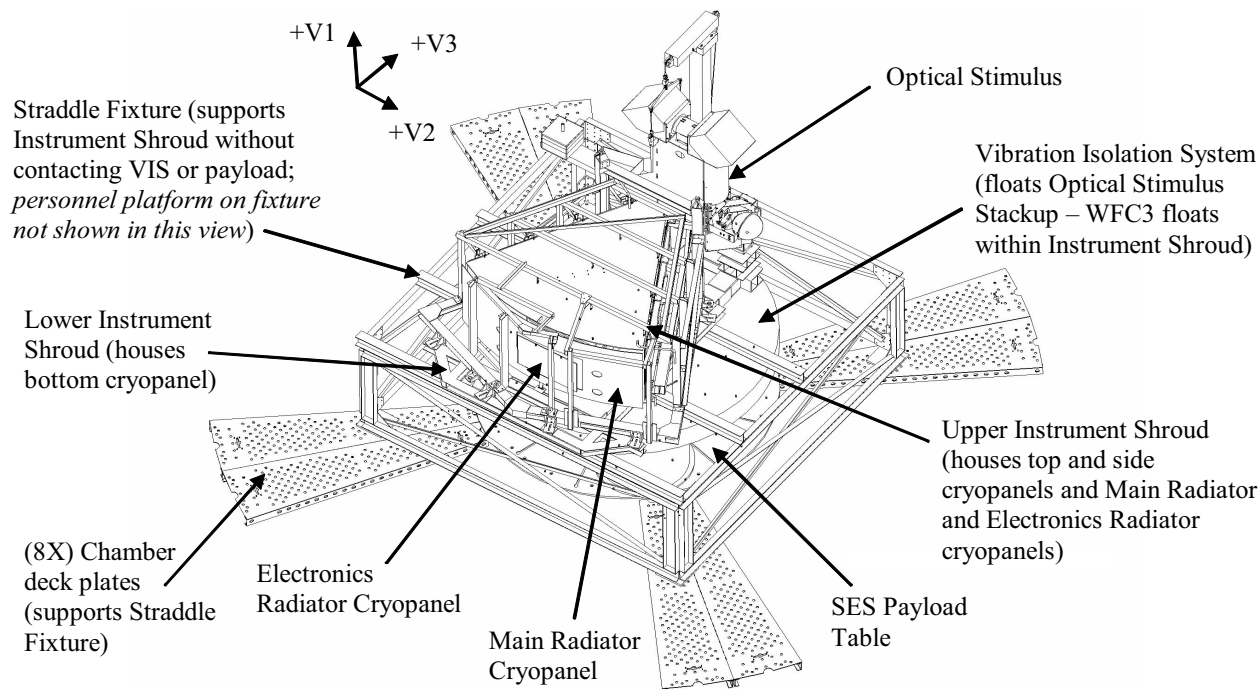


Figure 5 – Overview of TV1 and TV2 Test Setup

4. POST-TV1 CORRELATION LESSONS LEARNED

After the initial TV1 correlation effort, the model was handed off to another organization and a new team was responsible for upgrading and maintaining the model. The baseline model as received was suitable for the TV configuration only, including constant powers as measured in test. After a thorough review of the model, some major shortcomings of the test and analysis were revealed, yielding the following lessons learned:

1. Ensure that the thermal design can be tested
2. Ensure that the model has sufficient detail for accurate predictions
3. Ensure that the power associated with all active control devices is predicted
4. Avoid unit changes for legacy models

4.1 ABILITY TO TEST

The design decision to allow vertical spreaders was based on the conclusion that this was a common practice in other flight designs and of low risk. However, what was not fully considered was the local impact of this on TECFIRE. Ground cooling loops were used to compensate for the non-functioning vertical spreaders masked the increase/decrease of the TECFIRE power necessary to maintain the desired setpoints. By controlling the temperature of the radiator (i.e. the hot side of the TEC), the radiator temperature was not allowed to respond to changes in the power dissipation by TECFIRE as it would in flight. Therefore, in essence, the design was tested upstream of the radiator, but not end to end. This presented a risk to design verification, but the design had matured too far to allow for changes.

It is critical that a thermal design be ground testable. If it is unavoidable to adhere to this, the consequences of deviating from flight conditions must be thoroughly understood.

4.2 SUFFICIENT MODELING DETAIL

The received model was also lacking in detail in the detector region, with only the outer shielding (IR Cold Enclosure and UVIS Housing) being represented for the detectors. This made it impossible to predict the TEC power needed to cool the CCD or the IR FPA. The model was upgraded to include the detailed detector models as well as the detailed IR Cold Enclosure model and provided better representation to align with flight telemetry, where previously no representation existed. Furthermore, the inclusion of the detectors themselves allowed for the use of a SINDA routine to be developed³ to model the TEC operation including its contribution to the thermal model predictions. The WFC3 model was upgraded to include this capability for the UVIS 4-stage, UVIS 2-stage (constant current), IR 6-stage, and TECFIRE TECs. The performance curves of each TEC (relating DT to current and hot side temperature) were scaled to match the power output and performance as seen in test. With the exception of TECFIRE at a later point in time, the TEC performance curves were not measured independently from the vendor supplied data, but in general agreed fairly well based on test data.

Also, the model included some artifacts of Hot/Cold biasing that were not removed during the initial correlation. These included the use of degraded optical properties for the internal Optical Bench coating and the use of different gas charges in the GCHP for hot and cold cases, with the hot case including twice as much