James Webb Space Telescope Integrated Science Instrument Module Thermal Balance/Thermal Vacuum Test Configuration and Test Planning at NASA's Goddard Space Flight Center

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The James Webb Space Telescope (JWST) is the next of the "great observatories", scheduled to be launched in 2014. Three of the four science instruments are passively cooled to their operational temperature range of 36K to 40K, and the fourth instrument is actively cooled to its operational temperature of approximately 6K. Thermal-vacuum testing of the flight science instruments at the Integrated Science Instrument Module (ISIM) element level will take place within a newly constructed shroud cooled by gaseous helium inside Goddard Space Flight Center's (GSFC) Space Environment Simulator (SES). The test enclosure surrounding the instruments during the integrated ISIM-level thermal balance testing is complex, and is designed to simulate as closely as possible the in-flight conductive and radiative thermal environment around the ISIM. Thermal control and measurement of parasitic sources of heat leak into the test volume is critical, as the dissipation plus known parasitics in the flight ISIM is approximately 454 mW, and additional parasitics attributed to the flight enclosure itself are nearly equal to this, resulting in the energy balance of the in-flight ISIM being less than 1.0 W. Sources of test-induced parasitics must be carefully controlled and measured, and the ability to thermally control the test environment is critical to enable accurate thermal balance testing and thermal model correlation. This paper describes the test configuration and plans for the ISIM-level thermal vacuum/thermal balance testing at GSFC.

I. Introduction

The James Webb Space Telescope (JWST) is the next of the "great observatories", designed to be launched into orbit around the second Lagrange point in 2014. It has a 6.5 m (deployed) multi-faceted mirror, and its science instruments operate in short to medium wavelengths, to enable insights to the formation of the galaxies and planets following the "Big Bang". NASA's Goddard Space Flight Center (GSFC) is the mission lead, and is directly responsible for the Integrated Science Instrument Module (ISIM), including its integration and test. The suite of four science instruments, located in the cryogenic volume behind the primary reflector (denoted as Region 1), is comprised of the Near Infrared Spectrograph (NIRSpec), primarily sponsored by the European Space Agency (ESA) with substantial NASA contribution; the actively cooled Mid Infrared Instrument (MIRI), jointly sponsored by ESA and the European Consortium (EC) with support from the Jet Propulsion Laboratory (JPL); the Fine Guidance Sensor (FGS), provided by the Canadian Space Agency (CSA); and the Near Infrared Camera (NIRCam), provided by NASA. In flight, NIRSpec, NIRCam, and FGS are cooled to the range of 36 to 40K passively via heat transfer through complex high-purity aluminum thermal links to dedicated radiators, while the MIRI is actively cooled to approximately 6K. NASA provides the cooler and supplemental hardware for MIRI. The cooler's compressor is

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located in the ambient temperature spacecraft bus, outside the cryogenic Region 1. The science instruments are mounted on the ISIM structure, a special composite truss structure designed for exceptional optical stability, provided by NASA. The Observatory Prime Contractor is Northrop Grumman Aerospace Systems (NGAS).

Figures I-1 and I-2 illustrate the observatory and the major components of the ISIM, respectively. The ISIM Electronics Compartment (IEC), in close proximity to Region 1, houses the instrument and detector control electronics, and operates at approximately ambient temperature. It is denoted as "Region 2". The ISIM Harness Radiator (IHR), which operates below 80K and is also provided by ISIM, rejects most harness parasitic heat loads to space before the harnesses enter Region 1. The ISIM Thermal Control Subsystem provides 93 flight housekeeping temperature sensors on the instruments, ISIM structure, radiators, and other locations, and trim heaters to guarantee minimum instrument operational temperatures. It arranges for control of contamination control heaters on each instrument (except the MIRI), to avoid contamination during post-launch cooldown, and in the event of contamination on-station.

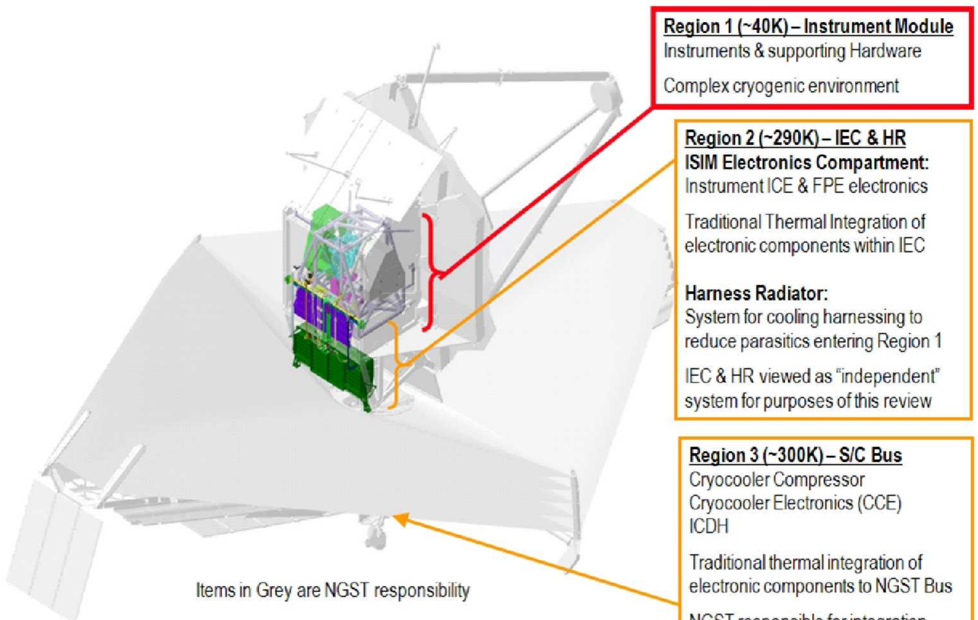

Figure I-1. JWST Observatory

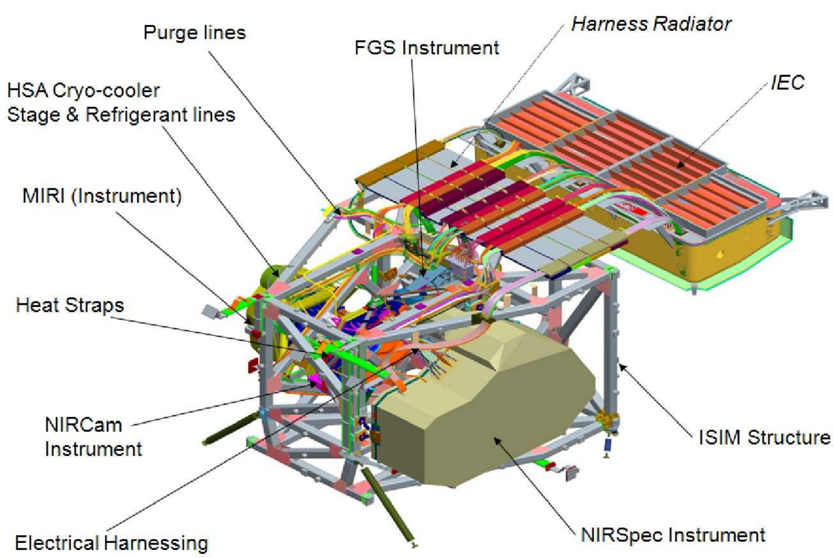

Figure I-2. Integrated Science Instrument Module, with Harness Radiator and Integrated Electronics Compartment

Previous papers[1,2] have described the general characteristics of the James Webb Space Telescope (JWST). Since those papers were written, some important changes have taken place in the observatory thermal design and the test program. First, the method of cooling the MIRI science instrument to approximately 6K has changed from solid hydrogen stored within a dewar to a closed cycle mechanical cooler. While this potentially lengthens the observing time for the instrument, the cooler has a limited design heat lift capability, and the total heat load to the first stage must fall within that capability in order for the instrument to reach its operational temperature. Initial thermal balance tests of the Verification Model of the MIRI indicated slightly higher radiative heat loads than originally predicted through its multi-layer insulation (MLI), when exposed to the worst case hot 41K thermal environment inside the ISIM. To recover lost margin to the cooler's heat lift capability, the MLI covering the instrument was redesigned by the instrument team, and a decision was made by NASA (responsible for the ISIM) to provide a radiative "shield" around the MIRI within the ISIM enclosure. The shield is to be cooled to approximately 18K by means of a conductive link to the cooler's second stage. Detail design of the shield is ongoing at this time.

II. Overview of Facilities Used for ISIM-level Thermal Vacuum Testing

The thermal test program of the ISIM has evolved substantially since 2007; most notably, the decision was made to forego thermal vacuum/thermal balance testing of the Engineering Test Units (ETU) of the instruments at the integrated ISIM level. This resulted in the decision to produce only a single protoflight ISIM structure, rather than a prototype and flight unit. Current plans still call for pre- and post-vibration thermal vacuum/thermal balance testing, combined with optical, electrical, and other performance testing at the Goddard Space Flight Center for the flight units, prior to integration with the Optical Telescope Element (OTE) and subsequent thermal vacuum testing at the Johnson Space Center (JSC). The thermal tests at the ETU level were originally intended for risk reduction, providing performance confirmation at an early stage. They were also to be used as a "dry-run" or pathfinder, for the flight unit tests at the ISIM-level, verifying that: 1) test Ground Support Equipment (GSE) and test procedures were designed correctly and performed adequately to yield desired test conditions; 2) test profiles were optimized and facility capabilities were well understood and matched to the test needs; 3) test-induced parasitic heat loads were characterized and quantified, and would not interfere with model correlation; and 4) instrumentation measurement accuracy would be adequate for thermal model validation. It was desired to obtain this information prior to the flight unit testing because of the high cost of the test in the Space Environment Simulator (SES), NASA GSFC's largest thermal vacuum chamber, and the projected test durations of nearly five months per test. Further, because the total heat load to the flight units is expected to be less than 1.0 watt, it is likely that small unknown sources of parasitic heat would not manifest themselves until flight unit temperatures approached operational balance conditions, occurring approximately 30 days after the test start.

A new removable and reconfigurable Gaseous Helium (GHe) shroud was recently designed and fabricated to support JWST testing at GSFC. It was designed with a diameter of 7.62 m (25.5 ft), and fits within the fixed LN_2 shroud which has a diameter of 8.23m (27.0 ft) inside the SES. Figures II-1 and II-2 show the GHe shroud in two different height configurations which will be used for: 1) ISIM-level thermal vacuum/thermal balance (TV/TB) testing; and 2) Optical Telescope Element (OTE) hardware thermal testing, respectively (the non-ISIM OTE test article is larger than the ISIM). In the configuration supporting the ISIM-level testing, the GHe shroud has an enclosed height of 4.57 m (15.0 ft), while in the OTE test configuration its enclosed height is 8.37 m (27.5 ft). A more complete description of the new helium shroud, including performance capabilities obtained from initial tests, is given in a companion paper[3]. As shown in Figure IV-3, the flight ISIM and associated GSE will be completely enclosed within the upper volume during ISIM-level TV/TB testing, which is cooled with GHe to approximately 18K. The Optical Simulator (OSIM), a critical piece of optical GSE used to evaluate instrument optical performance, is positioned beneath the cooled GHe shroud floor, and provides a beam into the instruments pick-off mirrors from below. The OSIM must be kept at 100K, so it is surrounded by the facility's fixed LN_2 shroud, partially blanketed, and controlled to a stable temperature with heaters. Similarly, the large Vibration Isolation System (VIS), upon which the entire flight ISIM is supported from the chamber floor, must operate at ambient temperature. It too is beneath the helium shroud, and is heavily blanketed and heated to maintain it at ambient temperature. Its heat load ultimately goes to the chamber Nitrogen shroud system.

Figure II-1. SES GHe Shroud in -01 (ISIM) Test Configuration

Figure II-2. SES GHe Shroud in -03 (OTE GSE) Test Configuration

The JWST and ISIM management have defined a series of precursor thermal tests in the SES facility, designed to incrementally check nearly all aspects of the facility and GSE performance prior to thermal vacuum testing of the flight ISIM. Figure II-3 is a timeline of the major ISIM tests currently scheduled in the SES. The first facility test was the He Shroud Configuration -03 Acceptance Test in June 2009. This reflected the larger He shroud configuration which will support the OTE CryoSet test. The second facility test was the SES Chamber Hardware Certification Test in early 2010 which reflected the smaller -01 configuration. Test results were excellent, confirming adequate He refrigerator heat lift capacity, reliability, shroud temperature stability and gradient control, and vacuum retention. Those tests have also helped evaluate: planned test procedures; adequacy of the thermal control hardware affixed to critical GSE; operational performance characterization of the specialized photogrammetry equipment and its thermal control system; and dimensional alignment stability of the critical ISIM Test Platform (ITP), used to support the flight ISIM in test. Additional follow-on tests include:

1. Cryo-Set test of the flight ISIM structure, in which the structure is thermally cycled several times from ambient to cryogenic temperature, while its optical alignment and stability are measured in-situ with the specialized photogrammetry equipment;
2. Cryo-Proof test of the flight ISIM structure, which verifies its structural integrity and alignment stability using mass simulators in place of the flight instruments;
3. OSIM CryoCal test of the OSIM optical GSE, which verifies its performance at cryogenic conditions;
4. OTE Cryo-Set test, which exposes the flight OTE backplane structure to thermal vacuum cycling from ambient to cryogenic temperatures;
5. Cryo-Vac Test #1, the pre-vibration thermal vacuum and thermal balance testing of the flight ISIM;
6. Cryo-Vac Test #2, the post-vibration thermal vacuum and thermal balance testing of the flight ISIM.

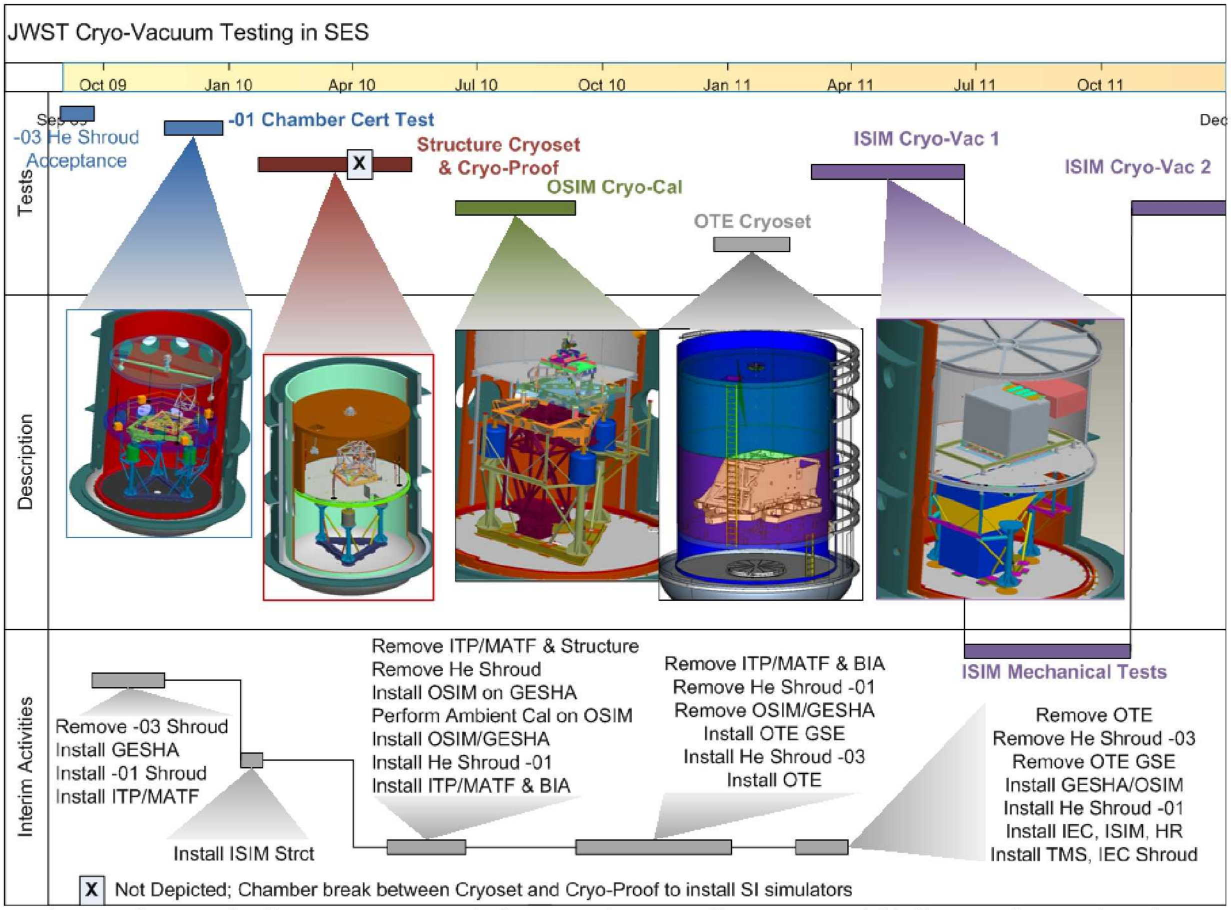

Figure II-3. JWST Cryo-Vacuum Tests in Space Environment Simulator at NASA Goddard Space Flight Center

III. Flight ISIM-level Cryo-Vac Thermal Test Objectives

The flight ISIM must be fully verified at the ISIM-level at GSFC before it is integrated to the OTE. As a result, the thermal test environment provided in the ISIM-level Cryo-Vac tests must be flight-like to permit realistic performance verification and characterization of the ISIM instruments, their optics, electronics, software, and all other subsystems. Detailed thermal requirements are defined for instrument temperature control, thermal stability, electrical harness parasitics, heat transfer to the instrument radiators, contamination avoidance during cooldown and decontamination (if needed) on-station, etc. The absence of the flight thermal environment to the ISIM, plus the presence of substantial GSE, makes it difficult to reproduce precisely the cryogenic flight environment in test. Thus, while there is a strong desire to verify by test as many thermal requirements levied on the ISIM Thermal Control Subsystem as possible, the final verification for many will take place by analysis using a thermal model correlated with test data.

Key ISIM-level Cryo-Vac test objectives leading to thermal system verification and characterization include:

- ISIM thermal model validation;
- Multi-Layer Insulation (MLI) performance and workmanship;
- End-to-end (instrument to radiator) heat strap thermal conductance at operational temperatures;
- Heat transfer to the instrument radiators;
- Harness parasitic radiator performance and parasitic harness heat loads to ISIM structure, each instrument, and to the Backplane Support Fixture (BSF) (to which ISIM is mounted);
- Performance (adequacy), workmanship of housekeeping temperature sensors and operation of contamination control heaters/control algorithms during cooldown and warmup;
- Trim heater capability to meet minimum operating temperature requirements for the instruments in general, and their Application Specific Integrated Circuits (ASIC);
- Science instrument transient stability during multi-instrument operation;
- Sensitivity of ISIM to backplane interface temperature;

- MIRI thermal performance, heat load measurement, within shield enclosure;
- IEC thermal balance, cycling, transient stability, steady state surface and box mounting temperatures

IV. Flight ISIM-level Cryo-Vac Test Configuration, Test Planning

The ISIM element will provide a flight-like thermal environment to the Region 1 components during the Cryo-Vac tests.

A. Thermal Environment Simulation

Close inspection of the ISIM components in Region 1 reveals that there are 18 conductive interfaces to the surroundings, illustrated in Figure IV-1. These interface points include kinematic mounts between the ISIM structure and the BSF, heat strap attachments to instrument radiators (and mechanical mounting to the BSF in a few locations), and a purge line interface. The complete radiative environment surrounding the flight ISIM in Region 1, made up primarily by the "ISIM Enclosure" (provided by the prime contractor), may be approximated with 10 discrete surfaces (the conical Aft Optics volume, present in the flight observatory, is not simulated in test). Figure IV-2 shows these 10 radiative interfaces to Region 1.

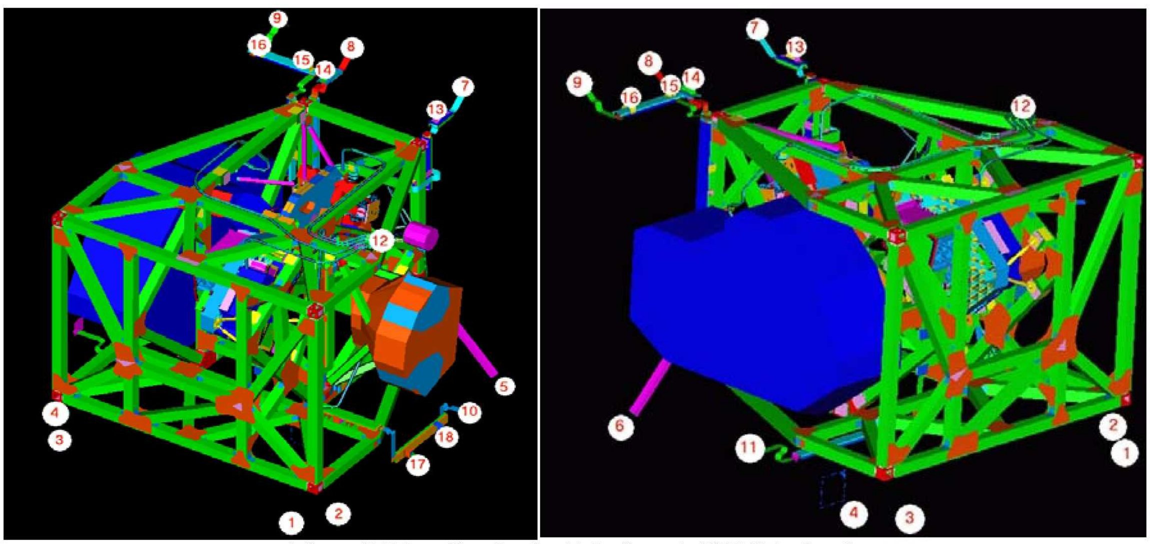

Figure IV-1. Conductive Interfaces to ISIM Region 1

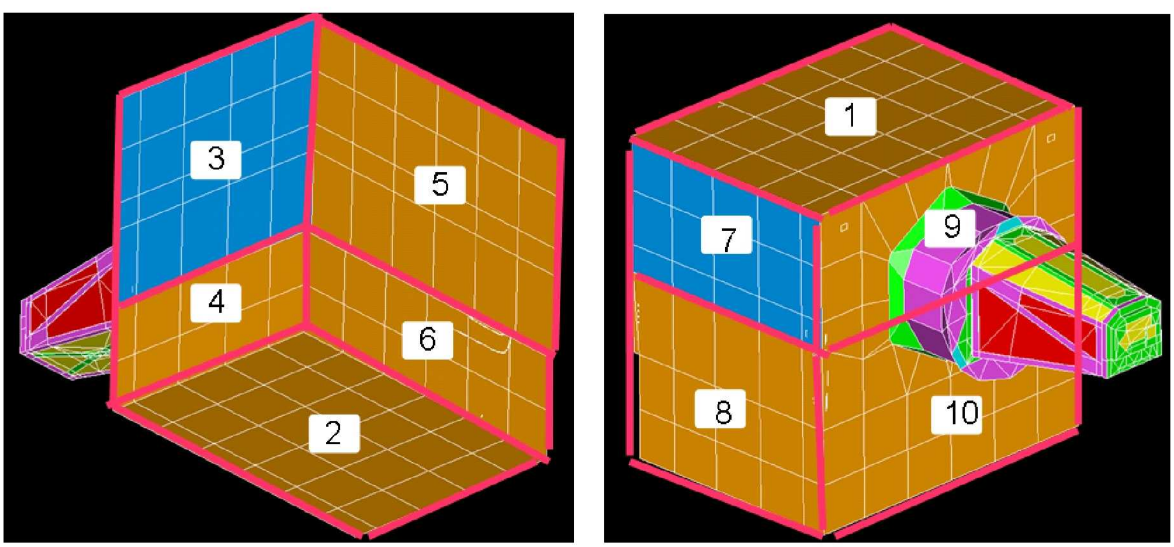

Figure IV -2. Radiative Interfaces Surrounding ISIM Region 1 (simulating ISIM Enclosure)

Each of the 18 conductive interfaces to Region 1 identified above will be simulated in test with individually temperature controlled GSE, since neither the flight BSF nor the instrument radiators are present during the ISIM-level Cryo-Vac tests. The ITP, a GSE invar structure designed to simulate the structural mounting characteristics of the flight BSF, replaces it during the test. The flight thermal links, or heat straps, that attach the NIRSpec instrument, NIRCam instrument, FGS instrument, NIRSpec detector and ASIC, and the MIRI support structure mount feet and harnesses to their respective radiators for thermal control, will be attached in test to individually controlled heat sinks through specially designed "Q-meters" (simple devices that measure heat flows). The BSF purge line will also be temperature controlled at the interface to the ISIM. Similarly, each of the 10 radiative panels provided in test are to be individually temperature controlled, with ISIM-facing surfaces covered with the same materials and/or coatings as the flight ISIM enclosure. The GSE conductive and radiative thermal interfaces provided in test, its support structures, plus all included thermal control and measurement instrumentation, constitute the Surrogate Thermal Management System (STMS). The STMS conductive and radiative interfaces are listed in Tables IV-1 and IV-2, respectively.

Table IV-1. Conductive Interfaces to ISIM Region 1

I/F	Interface Location	Controlled STMS Location
1	-V2/-V3 KM – Bipod leg A (-V3)	At ITP KM mount point
2	-V2/-V3 KM – Bipod leg B (+V3)	At ITP KM mount point
3	+V2/-V3 KM – Bipod leg A (-V3)	At ITP KM mount point
4	+V2/-V3 KM – Bipod leg B (+V3)	At ITP KM mount point
5	-V2 Monopod KM	At ITP KM mount point
6	+V2 Monopod KM	At ITP KM mount point
7	Heat Strap I/F to Radiator: NIRCam	At Q-meter I/F to heat strap
8	Heat Strap I/F to Radiator: NIRSpec FPA/ASIC	At Q-meter I/F to heat strap
9	Heat Strap I/F to Radiator: NIRSpec OA	At Q-meter I/F to heat strap
10	Heat Strap I/F to Radiator: MIRI	At Q-meter I/F to heat strap
11	Heat Strap I/F to Radiator: FGS	At Q-meter I/F to heat strap
12	Purge line I/F to BSF	At external GSE I/F to purge line
13	Heat Strap support I/F to BSF: NIRCam	At external GSE I/F to heat strap supports
14	Heat Strap support I/F to BSF: NIRSpec FPA/ASIC	At external GSE I/F to heat strap supports
15	Heat Strap support I/F to BSF: NIRSpec OA (1)	At external GSE I/F to heat strap supports
16	Heat Strap support I/F to BSF: NIRSpec OA (2)	At external GSE I/F to heat strap supports
17	Heat Strap support I/F to BSF: MIRI (1)	At external GSE I/F to heat strap supports
18	Heat Strap support I/F to BSF: MIRI (2)	At external GSE I/F to heat strap supports

Table IV-2. Radiative Interfaces to ISIM Region 1

I/F	Controlled STMS Surface
1	+V3 Enclosure Panel
2	-V3 Enclosure Panel
3	+V2/+V3 Enclosure Panel
4	+V2/-V3 Enclosure Panel
5	-V1/+V3 Enclosure Panel
6	-V1/-V3 Enclosure Panel
7	+V2/+V3 Enclosure Panel
8	+V2/-V3 Enclosure Panel
9	+V1/+V3 Enclosure Panel
10	+V1/-V3 Enclosure Panel

The flight Instrument Electronics Compartment (Region 2) will be present in test, but it will be entirely enclosed within a double shroud. An inner shroud cooled with LN_2 will accept most of the 230W (allocated) of heat load from the electronics boxes.An outer GHe cooled shroud will maintain an exterior surface temperature consistent with the GHe chamber shroud. This prevents "pollution" of the GHe chamber shroud volume with short wavelength energy which might leak into the critically controlled Region 1 within the STMS. Similarly, the flight Instrument Harness Radiator, designed to minimize heat transfer to Region 1 from the harnesses as they transition from the ambient temperature Region 2 IEC, will be provided a separate temperature controlled environment.

Radiative panels of the STMS will be plumbed for transport of GHe from the facility refrigerator for rapid transition to cryogenic temperature at the start of the test, and for radiant environment control to prevent contamination at the test conclusion. Once the panels reach their approximate operational temperatures, the helium flow in each panel will be stopped, and fine temperature control will be provided by heat strap connections to coldplates plus controlled heat addition. Conductive interfaces to the ISIM structure are provided by individually temperature controlled ISIM kinematic mount surfaces on the ITP (the ITP itself incorporates GHe cooling lines and heater control). Temperature sensors and controlled heater circuits at each controlled conductive interface point and on each temperature controlled radiant panel will be fully redundant to ensure test continuity throughout the estimated 5-month duration of each Cryo-Vac test. Table IV-3 lists preliminary thermal control and measurement requirements for the STMS radiative surfaces and conductive interface points.

Table IV-3. Preliminary Thermal Control Requirements for STMS Panel and Interface Points

Parameter	Cryo: Balance	Cryo: Non-Balance	Transition from Ambient to Bakeout, or from Bakeout to Cryo, or from Cryo to Ambient				
Controlled I/F and Panel Temperature range (K)	30 to 50	30 to 50	18 to 50	50 to 100	100 to 200	200 to 313	313 to 370
I/F Point and Bulk Average Panel Temp. Accuracy (K)	±0.1	±0.2	±0.2	±0.5	±2.0	±3.0	±3.0
I/F Point and Bulk Average Panel Temperature Resolution (K)	0.03	0.03	0.033	0.1	1.0	3.0	1.0
Max. Allowed Gradient within each Panel (K)	2.0	2.0	2.0	5.0	7.5	10.0	10.0
Required Stability (K/hour)	±0.2*	±0.5	NA	NA	NA	NA	±3.0**
Max. Heat Load to/from interface point or panel (W)	0.5	0.5	1.0	5.0	20.0	20.0	20.0
Max. Rate of Change of I/F points and radiant panels during Transitions (K/hr)	NA	NA	20.0	20.0	20.0	20.0	20.0

* Over final 6 hours of balance ** During bakeout plateau only

Figure IV-3 illustrates the Regions 1 and 2 ISIM hardware in the STMS, as it will appear in the SES during the Cryo-Vac tests.

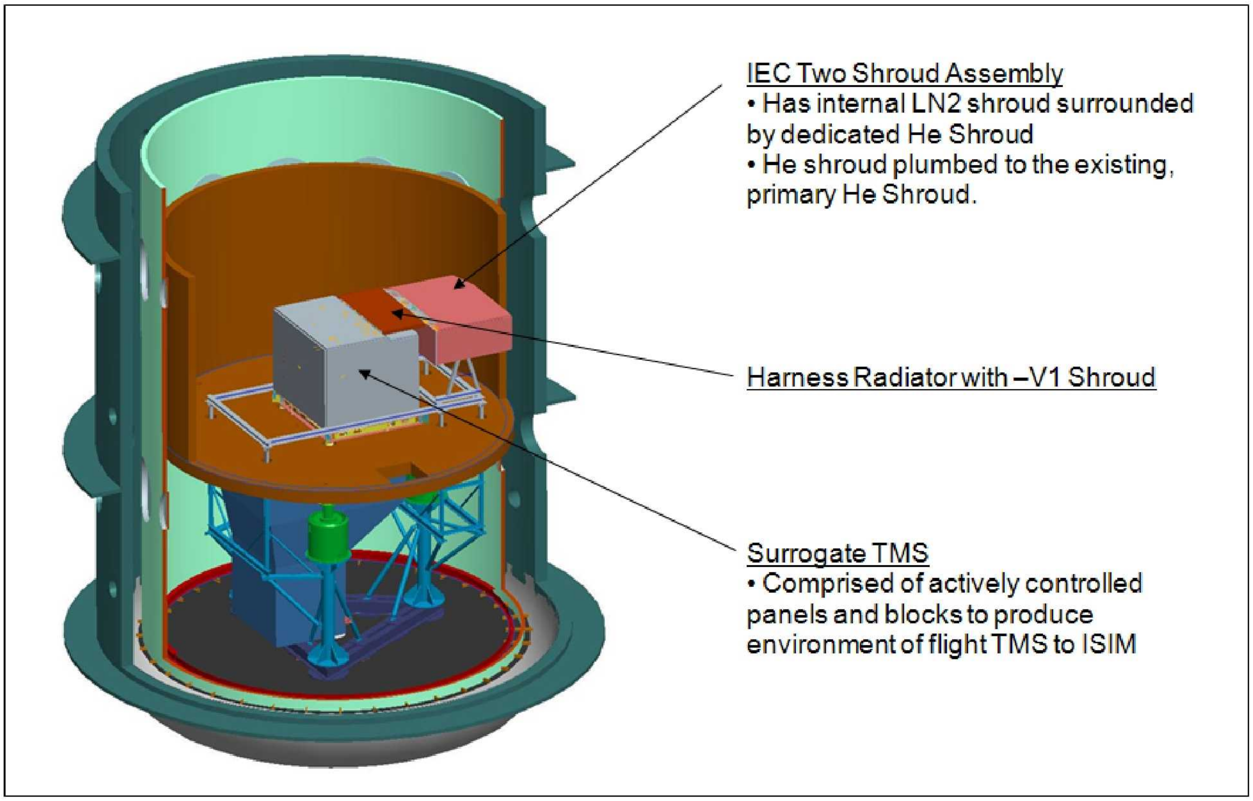

Figure IV-3. Test Configuration of ISIM Regions 1 and 2 inside the GSFC SES facility during Cryo-Vac testing

B. Q-meter Design Considerations

Model correlation will make use of the flight housekeeping temperature sensors mounted on the ISIM structure, science instruments, harness radiator, etc., plus flight science instrument temperature sensors. It is recognized also that Q-meter design and operation is of critical importance to thermal model validation. A schematic of a typical Q-meter is shown in Figure IV-4. The device as shown is designed to stabilize minor transient temperature fluctuations at the coldplate end (point C) by controlled heat addition at point B. Typically, the temperature at point A is controlled to the predicted radiator temperature that must be maintained in the balance condition. An alternative control approach has been suggested, however, in which temperature controllers are used at both points A and B to maintain a constant temperature difference across the section. Then, heat flow through the device in the test may be inferred by direct comparison of control heat added to that added during device calibration.

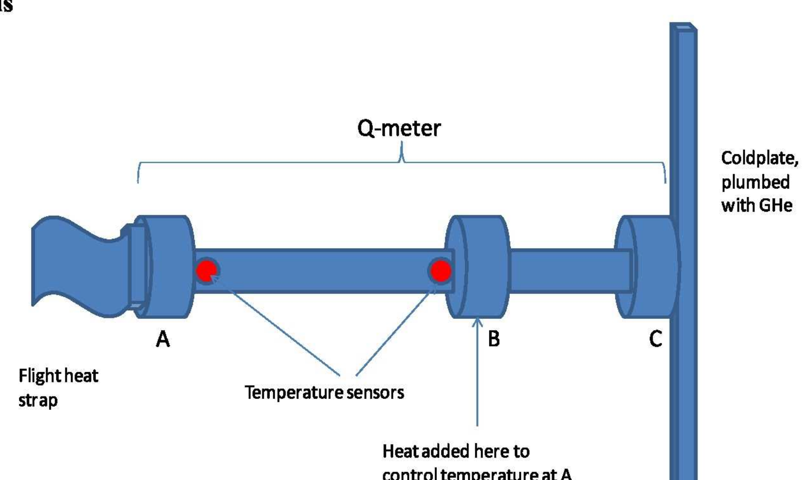

Figure IV-4. Schematic Design of Q-meter

This control approach yields the advantage of being insensitive to Q-meter temperature changes as it is approaching balance (the meter itself will not be absorbing heat). Both approaches will be investigated during calibration.

The Q-meters must be designed to provide adequate resolution of heat flows over the full predicted range under operational (thermal balance) conditions. This results in Q-meter design that provides sufficiently high thermal resistance at cryogenic operating conditions to provide measurable temperature differences across the devices with the predicted steady state heat flows. Temperature sensors across sections A and B in Figure IV-4 must have adequate resolution and repeatability to yield adequate heat flow measurement during the cryogenic balance conditions. In the ISIM Cryo-Vac tests, accelerated transient cooldown will be accomplished by setting all radiant panels and conductive interface points (including the Q-meters) as cold as possible quickly to draw heat out of the instruments and structure. This provides a competing design consideration for the devices: they must exhibit a low enough thermal resistance to heat flow at higher temperatures so that they do not unduly prolong the transient cooldown period. These design tradeoffs are being investigated at this time. Preliminary calculations indicate that the Q-meters, if designed of 6061-T6 aluminum to produce a 1K temperature drop across section A-B during balance conditions, would likely not extend the cooldown period to meet thermal balance stability criteria by more than 1 day. Table IV-4 lists preliminary thermal control and heat flow measurement requirements for the ISIM Q-meters.

Table IV-4. Preliminary Thermal Control Requirements for STMS Q-meters

Parameter	Notes	NIRSpec OA	NIRSpec FPA/ASIC	NIRCam	FGS	MIRI
Predicted min. heat flow at operating conditions, test/flight (mW)	1	61	60	180	79	47
Predicted max. heat flow at operating conditions, test/flight (mW)	1	98	93	202	99	61
Required minimum design heat flow to be measured at cryo balance (mW)	2	15	15	45	20	12
Required maximum design heat flow to be measured at cryo balance (mW)	2	400	400	800	400	250
Required heat flow accuracy at cryo balance (operating conditions) (mW)	3	3	3	9	4	2
Required heat flow resolution at cryo balance (operating conditions) (mW)	4	1.5	1.5	4.5	2	1
Temperature Stability Required at Location "B" during cryo (balance) (+/- mK/hr)	5	7.5	20	20	2	20
Temperature Stability Required at Location "B" during cryo (non-balance) (+/- mK/hr)	6	33	33	33	33	33
Maximum increased time to achieve thermal balance from ambient cooldown with Q-meters vs. no Q-meter (days)		2	2	2	2	2

Notes:

1. Taken from ITCS CDR Package, Section 7 (Shaun Thomson), 3-4 March, 2009, p.7-83
2. Minimum flow taken as 1/4 min. predicted from (1). Maximum flow take as 4 times the max predicted from (1). (Min/max q-meter calibration limits)
3. Required Accuracy =5% of minimum predicted strap heat flux
4. Required resolution = half of accuracy
5. Required Q-meter thermal boundary stability = half of SI stability criteria at cryo for NIRSpec OA and FGS, 10% of stability criteria for NIRSpec FPA/ASIC, and ~25% NIRCam stability criteria. Stability criteria taken from ITCS CDR Package, Section 18 (S. Glazer, D. McGuffey), 3-4 March, 2009, p.18-55
6. Taken from flight requirement of 0.1K/10000 sec

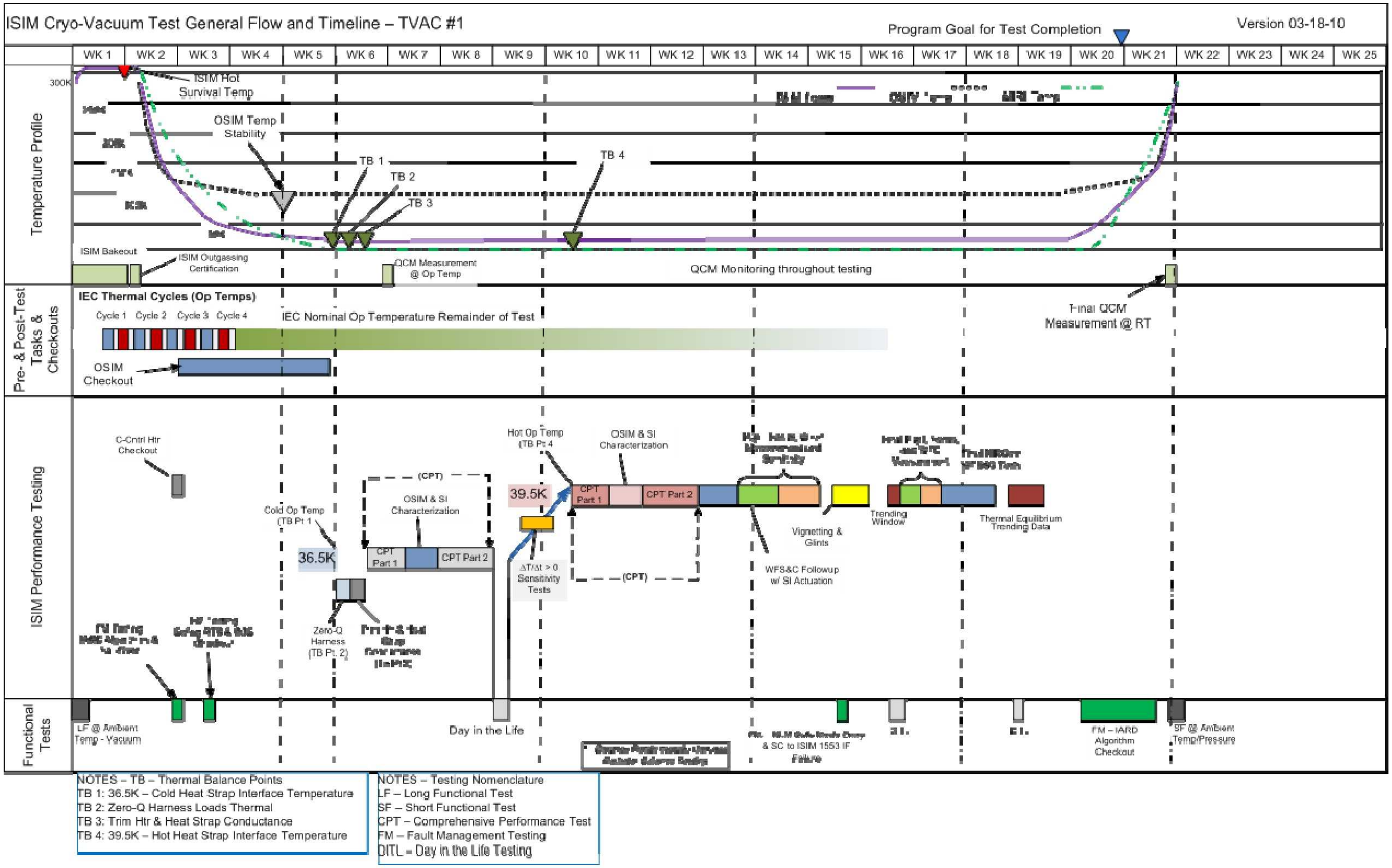

Figure IV-5. ISIM Cryo-Vac Test Profile

C. Test Profile

Intensive ISIM Cryo-Vac Test planning is underway to optimize test measurements while minimizing test times. Currently, both pre- and post-vibration Cryo-Vac tests are expected to last approximately 21 weeks. Figure IV-5 represents the current status of the test profile, and is subject to change as the test planning matures.

Note that the test plans currently call for four balance points;

1. Extreme cold thermal environment with very low instrument power dissipation;
2. Delta balance from (1), with zero-Q of harness heat loads to ISIM;
3. Delta balance from (2), with different trim heater power;
4. Extreme hot thermal environment with high instrument power dissipation.

Balance points 1 and 4 are designed to prove a viable thermal design over the full range of predicted thermal conditions, and to enable model validation over these ranges. Balance point 2 is accomplished by adjusting the temperature of the electrical harnesses as they leave the Instrument Harness Radiator to the same temperature as the ISIM structure attachment points, to provide adiabatic conditions. The difference in heat flows (as measured at the Q-meters, for instance), between balance points 1 and 2 will verify the magnitudes and physical locations of harness heat loads (while great efforts have been expended to predict harness parasitic heat loads, some significant modeling assumptions remain unproven). Balance point 3 is expected to yield information regarding heat strap (between instrument and radiator) end-to-end thermal conductance, plus additional information regarding instrument temperature sensitivity to trim heater power. Requirements for minimum heat strap end-to-end thermal conductance were established because of their impacts to Observatory thermal margins. Maximum heat strap end-to-end thermal conductance requirements were also developed to guarantee that contamination control heater circuits have adequate power to accomplish decontamination in flight. Thermal conductances of individual heat strap segments are being verified by the vendor by test at the component level, but because they must be fastened together in-situ during ISIM integration, joint conductances and their effects on end-to-end conductance cannot be verified until the ISIM Cryo-Vac tests.

D. Test Risks

The ISIM Cryo-Vac tests to be performed in 2011 and 2012 at GSFC are extremely complicated, involving complex thermal and optical GSE. The predicted magnitude of the combined dissipated and parasitic heat loads within the ISIM is less than 1.0 W, making quantification of parasitic heat loads, particularly from GSE and other unknown chamber sources, critical. Additionally, model correlation activities associated with other thermal vacuum/thermal balance tests in support of the JWST program have taken months, and have involved assumptions of environmental conditions and thermo-optical properties not readily available at the time of the test.

The possible inability to obtain reliable thermal balance data, and provide flight-like thermal conditions during the test has been recognized as one of the highest risks in the ISIM Risk database. This risk is heightened by the elimination of the ETU Thermal Vacuum test program. Mitigation of the risk is accomplished with the following activities:

1. Allocation of parasitic heat loads to major GSE, such as the OSIM and other optical GSE. Predicted parasitic loads are reviewed, and where possible, parasitics are to be measured in GSE component-level tests;
2. Maintenance of comprehensive lists of all GSE electrical harnesses, predictions of their estimated parasitic heat leaks, and attempts to heat sink the harnesses to specific locations in the test facility;
3. Preliminary characterization of parasitic heat loads in the helium shroud environment using bolometers (often "sneak" heat loads can emerge through vents, MLI closeouts, and small views of the Nitrogen shroud thermal environment);
4. Establishment of the incremental facility and GSE test program in the SES;
5. Constant communications with the instrument design teams throughout the JWST program, to exchange "lessons learned" by all teams during testing;
6. Requirement for key instrumentation and control assets to be fully redundant to minimize chances of test interruptions;
7. Continual re-evaluation and review of test plans by internal and external organizations.

IV. Conclusion

Thermal vacuum/thermal balance testing of the James Webb Space Telescope cryogenic flight Integrated Science Instrument Module requires the development of the extremely complex Surrogate Thermal Management System to provide realistic flight-like conditions to the payload, and make accurate heat flow and temperature measurements enabling model validation. Careful model correlation from test data will require fine resolution of expected dissipations and parasitic heat loads from test-induced sources at the milliwatt level. Intensive, multi-discipline integrated planning efforts are underway to optimize the test plans and test profile. Thermal test planning activities will focus on instrumentation accuracy/resolution adequacy for the test conditions, and detailed steady state and transient thermal modeling of the flight ISIM in the SES. While the test is challenging, and possibly represents one of the most complex cryogenic tests ever performed at the GSFC, current indications are that the testing will succeed in flight hardware verification and model validation.

Appendix. Acronyms

ASIC	Application Specific Integrated Circuits
BIA	Beam Image Analyzer
BSF	Backplane Support Fixture
CCE	Cryocooler Electronics
CSA	Canadian Space Agency
DM	Development Model
EC	European Consortium
ESA	European Space Agency
ETU	Engineering Test Unit
FGS	Fine Guidance Sensor
FM	Flight Model
FPA	Focal Plane Arrays
GESHA	Goddard Equipment Support Hardware Assembly
GHe	Gaseous Helium
GN_2	Gaseous Nitrogen
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
HR	Harness Radiator
HSA	Heat exchanger stage assembly
IEC	ISIM Electronics Compartment
I/F	Interface
IHR	ISIM Harness Radiator
ISIM	Integrated Science Instrument Module
ITP	ISIM Test Platform
JSC	Johnson Space Center
JWST	James Webb Space Telescope
K	Kelvin
KM	Kinematic Mount
LN_2	Liquid Nitrogen
MATF	Master Alignment Test Fixture
MIRI	Mid Infrared Instrument
MLI	Multilayer Insulation
NGAS	Northrop Grumman Aerospace Systems
NIRCam	Near Infrared Camera
NIRSpec	Near Infrared Spectrograph
OSIM	OTE Simulator
OTE	Optical Telescope Element
PG	Photogrammetry
PMBSS	Primary Mirror Backplane Support Structure
SES	Space Environmental Simulator
SI	Science Instruments
STMS	Surrogate Thermal Management System (for use in test)
TB	Thermal Balance
TMS	Thermal Management System (flight)
TV	Thermal Vacuum
VM	Verification Model
W	Watt

Acknowledgments

S.G. Author would like to thank Mr. D. McGuffey for use of graphics of test plans, Mr. S. Thomson for graphics illustrating ISIM flight and corresponding test configurations, and Mr. W. Bell and Mr. B. Comber for thermal model development and thermal analysis results.

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