ISIM ELECTRONICS COMPARTMENT DESIGN FOR THE JAMES WEBB SPACE TELESCOPE

Matthew Garrison, Keith Parrish, Charles Perrygo
NASA Goddard Space Flight Center

Charles Perrygo
Energy Solutions International, L.L.C.

ABSTRACT

The design of the James Webb Space Telescope calls for an enclosure, called the ISIM Electronics Compartment, to be mounted to a cryogenic structure underneath the scientific instruments and behind the telescope elements. This compartment must hold its electronics at room temperature and direct their power dissipations while minimizing the impact on the cryogenic environment of the observatory cold side. Directional baffles prevent the emission from directly heating the observatory, while conductive and radiative isolation prevent heat leaks through secondary paths. Current analysis shows that the existing design meets all key thermal requirements, allowing the ISIM Electronics Compartment to contribute to the functioning of the overall telescope.

INTRODUCTION

The James Webb Space Telescope (JWST) is an orbiting cryogenic infrared observatory with cold-side temperatures maintained by a large sunshield. The four scientific instruments onboard JWST are contained in the Integrated Science Instrument Module (ISIM) which is mounted to the Back Plane Support (BSF) behind the primary mirror. ISIM contains four instruments: the Mid-Infrared Imager (MIRI), the Fine Guidance Sensor (FGS), the Near-Infrared Camera (NIRCam) and the Near-Infrared Spectrograph (NIRSpec). The ISIM Electronics Compartment (IEC) is also mounted to the BSF and holds a number of high-power boxes, totaling 200 Watts of dissipation, at room temperature on the cold side of the sunshield. This is an order of magnitude above the summed dissipation of the remainder of the cold side. Its proximity to the cryogenic instruments is driven by the noise-sensitive science data that must be processed by electronics with the IEC.

This presents two significant thermal engineering problems: how to attach a warm compartment to a cryogenic structure, and how to safely dissipate the heat generated within without negatively impacting the remainder of the observatory cold-side. Conductive thermal isolation is obtained through an insulating structural core material and use of a launch/operational dual-load path structural mount. Six single-layer insulation (SLI) shields, multi-layer insulation (MLI) blankets and a parasitic tray radiator minimize the radiative heat exchange with cryogenic components. All heat sources are mounted to a conducting structural panel which also serves as a radiator. Directional baffles constrain the emission angles to minimize the load that the telescope and ISIM receive by direct illumination and reflections off of the sunshield.

Current analysis shows that this design is sufficient to meet the thermal requirements imposed by the JWST observatory. All analysis is done using TSS and SINDA/G in a modified fully-integrated observatory-level thermal model. Independent model verification is done at GSFC using IDEAS/TMG.

IEC DESIGN

The IEC structure is composed of three components: (1) four thermally-isolated K13 carbon-fiber face sheets and aluminum honeycomb equipment mounting panels that act as radiators on the outer side, (2) a composite tub that forms the remaining five sides of the compartment, and (3) the baffle housing that attaches to the radiator side of the mounting panels. These components are shown in the cut-away in Figure 1.

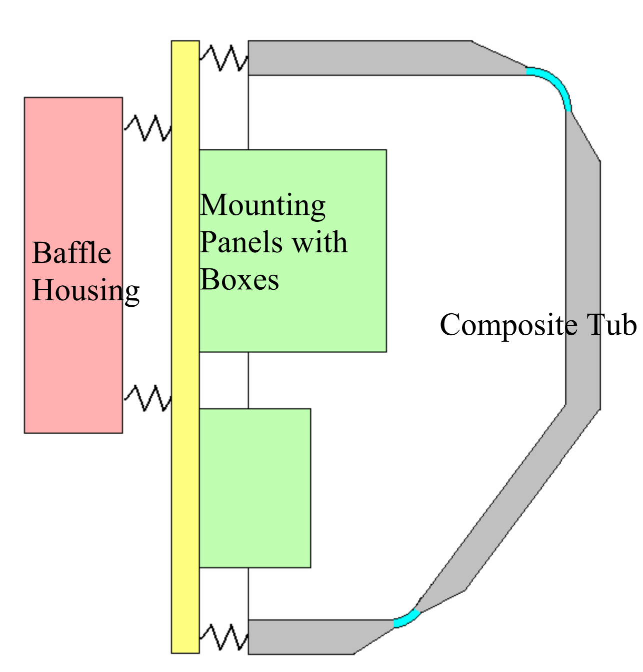

Figure 1: Cut-away of the IEC mechanical design

The mounting panels are four panels constructed of K13 face sheets and an aluminum core. The interior surface of each panel contains the required electronics boxes, heaters, thermisters, and any harness tie-downs required. Heat is conducted through the honeycomb to the outer face sheet, which has areas painted black in order to act as a radiator. Boxes are laid out so that each instrument nominally has a dedicated mount panel, except where FGS shares a panel with the ISIM Remote Servicing Unit (IRSU) and the NIRCam panel houses the DITCE. This allows substantial electrical isolation between the instruments and also allows them to operate within their required temperature range, 273 K to 313 K, even if neighboring instruments are forced to shut down.

The composite tub that forms the remaining five sides of the IEC compartment is a single component laid up with low thermal conductivity T300 carbon fiber face sheets. A low-conductivity Nomex core separates the inner and outer face sheets everywhere except the corners, where fiberglass standoffs prevent contact. Thermal isolation minimizes the heat flow from the warm mount panels to the colder tub structure.

The baffle housing is also mounted to the equipment mount panels using thermal isolators, this time on the outer face sheet. This structure is intended to hold the segments of the directional baffle in their correct alignment and to prevent heat leaks into them from the mount panels, which would result in an uncontrolled emission. Although the housing is not yet designed, thermal analysis is assuming that it is constructed of T300 face sheets and a Rohacell core to minimize thermal conductivity.

RADIATIVE THERMAL ISOLATION

The system that minimizes radiative heat leaks through uncontrolled paths consists of four parts: (1) MLI along the interior and exterior of most surfaces, (2) three SLI conformal shields that prevent heat leaking into the core area of the observatory, (3) three SLI diagonal shields that reduce radiation in the direction of the telescope and ISIM, and (4) a parasitic tray radiator that intercepts radiation to the ISIM floor. These are shown in Figure 2.

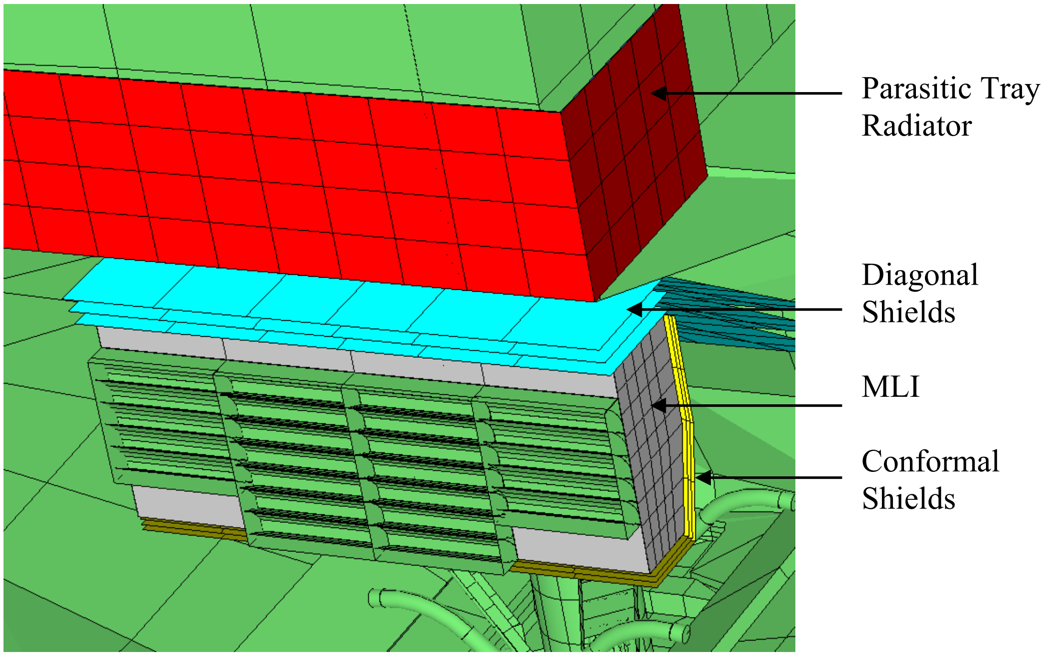

Figure 2: Radiative thermal isolation for IEC loads

The MLI covers all exterior surfaces of the IEC except for the black-painted radiator strips and all interior surfaces except for the mount panels. The blankets are assumed to have an ε^* of 0.03 with a black kapton outer surface.

Of the SLI shields, only the three conformal shields are considered part of the IEC; the diagonal shields are provided by Northrop Grumman Space Technologies (NGST). The goal of the conformal shields is to allow any radiation from the protected IEC surfaces to bounce around until it exits away from the observatory out either side or beneath the IEC. To allow this, all conformal shield surfaces are to be VDA except for the outermost surface, which is required to be high-ε and will be plain black kapton. The diagonal shields extend from the top surface of the IEC to the bottom of the Backplane Support Frame (BSF) and are currently modeled with VDA surfaces.

The parasitic tray radiator is also not considered part of the IEC subsystem, but it is important in preventing IEC parasitic heat leaks from warming the ISIM enclosure. It covers the ISIM floor, then wraps around the side and back by 0.8 meters, allowing the intercepted heat to conduct to those surfaces and from there radiates the heat to space.

CONDUCTIVE THERMAL ISOLATION

The IEC is conductively decoupled from the BSF through a dual load path. High-strength aluminum feet initially hold the 300 kg IEC in place, supporting the substantial launch. When the telescope deploys, these are separated from the conductive heat path and the IEC is instead suspended by three low thermal conductivity G-10 rods. These softer connections attach to the outer face sheet of the composite tub and only allow a conduction of 0.063 mW/K gradient with the structure.

EMISSION CONTROL

Because the electronics in the IEC will be dissipating 200 Watts throughout the mission, an effective system was designed to control the emission[1]. Two major heat paths were of concern: direct radiation from the IEC mount panels to the parasitic tray radiator, and emission to the sunshield that could reflect or be re-emitted back to the ISIM enclosure and radiators. The severity of the reflected radiation is a function of where the reflection occurs; the closer to the IEC and ISIM, the higher the probability that a photon will specularly or diffusely reflect towards the observatory instead of to space.

To this end, directional baffles were designed to constrain the radiation from directly illuminating the tray radiator and to minimize the heat impinged onto the sunshield. Each reflector cell consists of two parabolic and one circular reflector arranged around a radiator strip, as shown in Figure 3. Directional baffle performance is negatively constrained by three factors: (1) the limited ratio of area available for the baffles to area required for radiators, (2) heat conducted to the baffles and diffusely emitted, and (3) the lack of a perfect specularly reflective surface, allowing heat to be absorbed and diffusely re-emitted or to be diffusely reflected.

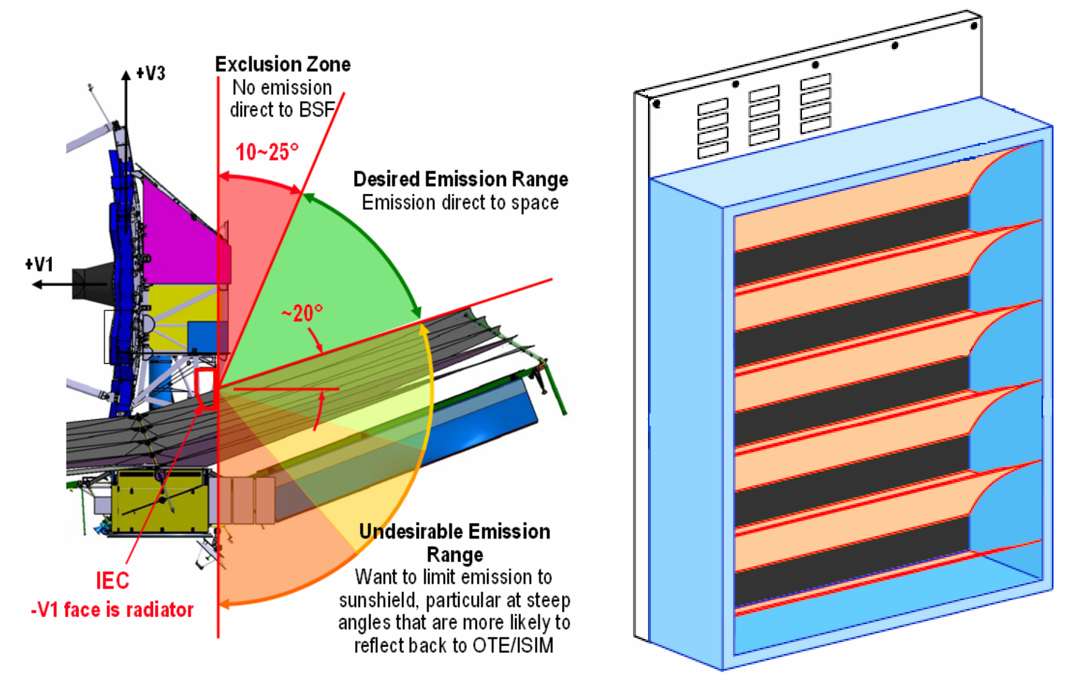

Figure 3: Radiation control regions (left) and directional baffle design (right)

IEC THERMAL ANALYSIS

As mentioned above, all thermal analysis is done on a detailed IEC model integrated into a full observatory model maintained by NGST. This is done to eliminate the complicated two-way interfaces between the IEC and the spacecraft, sunshield, ISIM and the telescope. The interior components of the IEC are approximated in the model, with harnesses modeled as black-body emitters and boxes represented by aluminum structures with the appropriate size, thermal mass and dissipation. Calculations are performed using TSS and SINDA/G. Due to the limitations of TSS, the parabolic sections of the baffles are represented by piece-wise cylindrical arcs with a maximum angular error between segments of 2 degrees. The design is assessed for steady-state thermal and baffle performance; transient analysis has not yet been completed.

STEADY-STATE PERFORMANCE

Steady-state results are used to validate two sets of requirements: the environment seen by the electronics boxes, required to be between 273 K and 313 K, and the maximum temperature of the composite tub's outer face sheets. The model was analyzed assuming steady-state box dissipations during normal science-taking observations. The resulting component temperatures are given in Figure 4 and Table 1, and the composite tub face sheet temperatures are compared with requirements in Table 2. In all cases, the current design shows compliance with requirements.

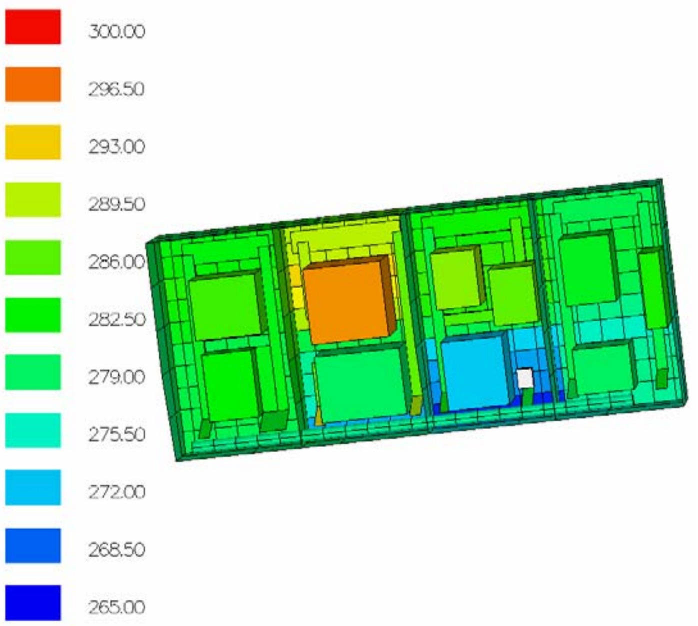

Figure 4: IEC temperature map during steady-state science-taking operations

Table 1: IEC Box temperatures and power dissipations

Box	Power Dissipation [W]	Predicted Temperature [K]
MIRI FPE	**18.5**	**286.3**
MIRI ICE	**18.5**	**284.0**
FGS	**44.3**	**296.2**
IRSU	**23.0**	**280.0**
NIRCam FPE1	**22.6**	**288.8**
NIRCam FPE2	**22.6**	**287.1**
NIRCam ICE	**8.0**	**273.3**
DITCE	**6.3**	**315.2**
NIRSpec FPE	**13.0**	**284.5**
NIRSpec ICE	**10.0**	**282.9**
NIRSpec MCE	**9.8**	**280.2**

Table 2: Composite tub outer face sheet temperatures and requirements

Face Sheet	Predicted Temperature [K]	Maximum Required Temperature [K]
+V1	**247.9**	**250**
+V2	**254.3**	**257**
-V2	**256.4**	**259**
+V3	**241.0**	**243**
-V3	**242.7**	**245**

The insulation discussed above limits the conductive heat load to the BSF to 35 mW and the radiative heat load to the ISIM closeout to 276 mW. Over 99% of the IEC-dissipated power is radiated to space before being absorbed by any cryogenic components.

BAFFLE PERFORMANCE

In order to assess the performance of the baffle system, the IEC model was run integrated into a representative geometry model for the sunshield and the ISIM floor, provided by NGST. The sunshield is broken into five zones, with a sixth defined as the ISIM floor. The maximum heat loads are provided from the IEC radiators, baffles and –V1 MLI to those zones. The representative surfaces, including the predicted and required heat loads, are shown in Figure 5. All zones currently meet their heat flow allocations.

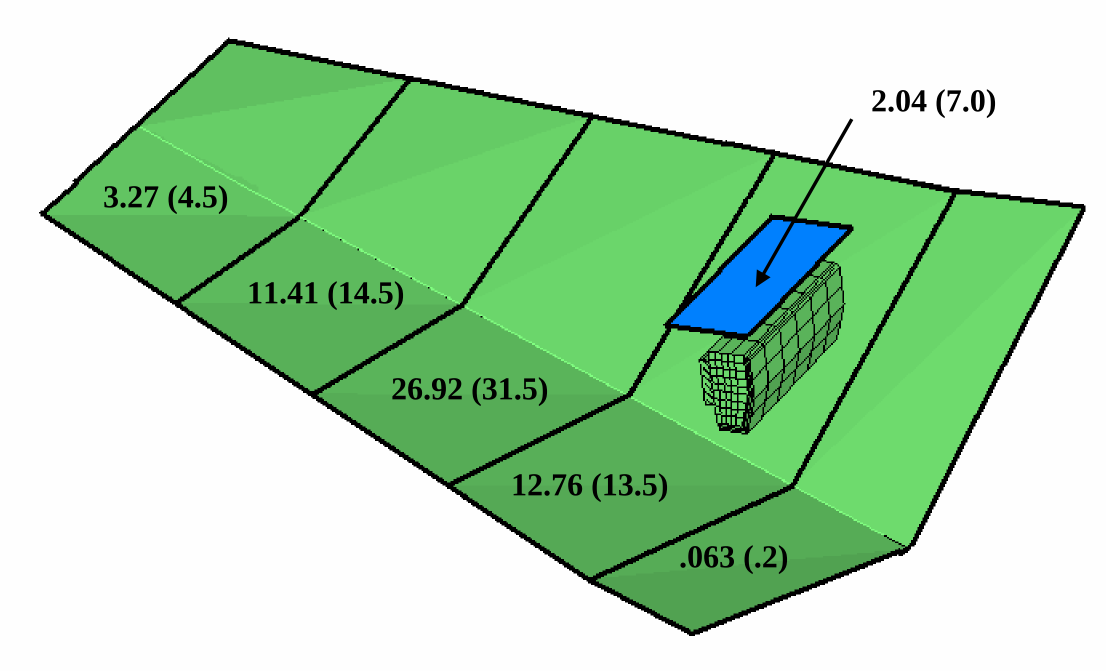

Figure 5: Heat impingements in Watts on the sunshield and ISIM floor representative surfaces during normal science operations, with requirements in parentheses

CONCLUSIONS

The IEC has been designed to hold room-temperature electronics boxes in close proximity to the cryogenic telescope and instrument module and to direct the 200 Watt dissipation so that is does not have a negative affect on the observatory performance. This is made possible through multiple radiative isolators in series, conductive isolation, and directional baffles. Analysis has shown that this design will meet the requirements levied on the IEC by the observatory, allowing the IEC to function as an integral part of the James Webb Space Telescope.

ACKNOWLEDGEMENTS

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1. Perrygo, Charles; Garrison, Matt, “Directional Baffles for Lateral Control of Radiator Emission Direction,” TFAWS 2006, College Park, MD.

CONTACT

Matthew Garrison
Mail Code 545
NASA Goddard Space Flight Center
Greenbelt, MD 20771
Phone: (301)286-1811
Email: Matthew.G.Garrison@nasa.gov

ACRONYMS

BSF	Backplane Support Frame
FGS	Fine Guidance Sensor
FPE	Focal Plane Electronics
GSFC	Goddard Space Flight Center (NASA)
ICE	Instrument Control Electronics
IEC	ISIM Electronics Compartment
IRSU	ISIM Remote Servicing Unit
ISIM	Integrated Science Instrument Module
JWST	James Webb Space Telescope
MCE	Microshutter Control Electronics
MIRI	Mid-Infrared Imager
MLI	Multi-Layer Insulation
NGST	Northrop Grumman Space Technologies
NIRCam	Near-Infrared Camera
NIRSpec	Near-Infrared Spectrograph
SLI	Single-Layer Insulation