THERMAL & FLUIDS ANALYSIS WORKSHOP

GSFC· 2015

ANALYTICAL METHODOLOGY USED TO ASSESS/REFINE OBSERVATORY THERMAL VACUUM TEST CONDITIONS FOR THE LANDSAT 8 DATA CONTINUITY MISSION

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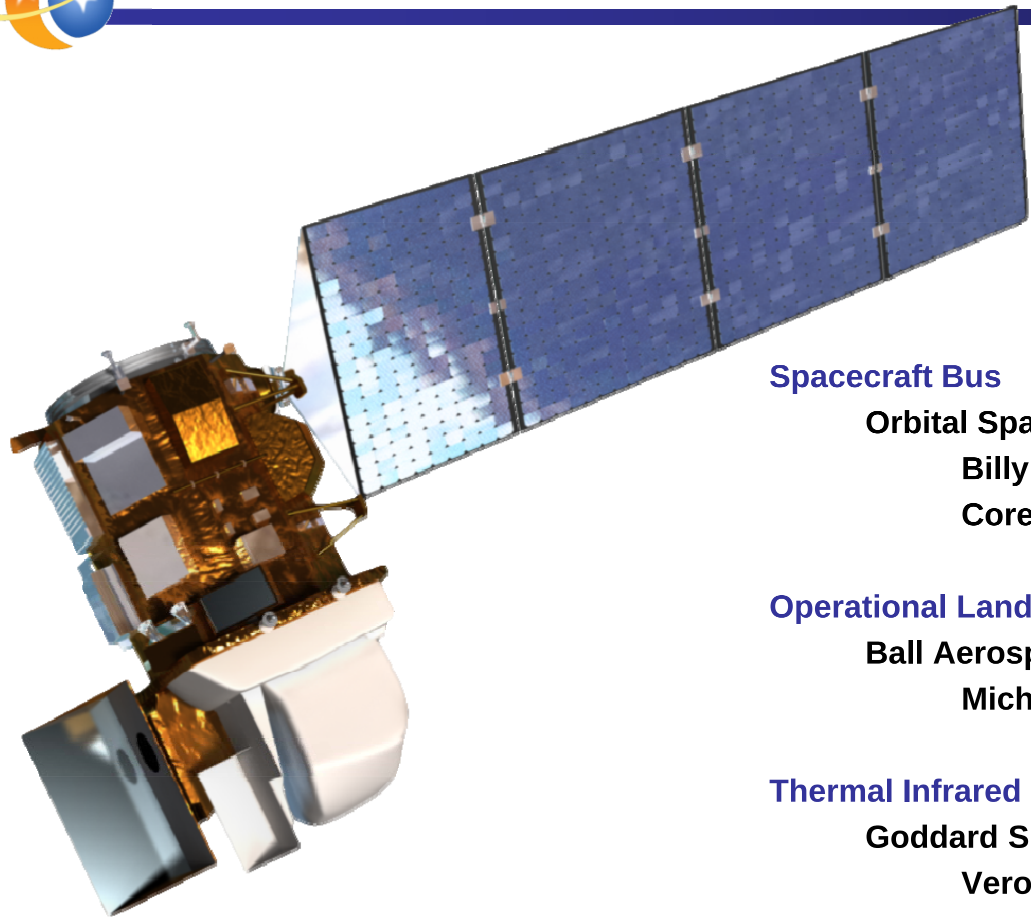

Spacecraft Bus

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Many thanks to a great team !

ABSTRACT

- The Landsat 8 Data Continuity Mission, which is part of the United States Geologic Survey (USGS), launched February 11, 2013.
- A Landsat environmental test requirement mandated that test conditions bound worst-case flight thermal environments.
- This paper describes a rigorous analytical methodology applied to assess/refine proposed thermal vacuum test conditions and the issues encountered attempting to satisfy this requirement.

Environmental Test Requirement

3.6.3 Thermal Balance Qualification

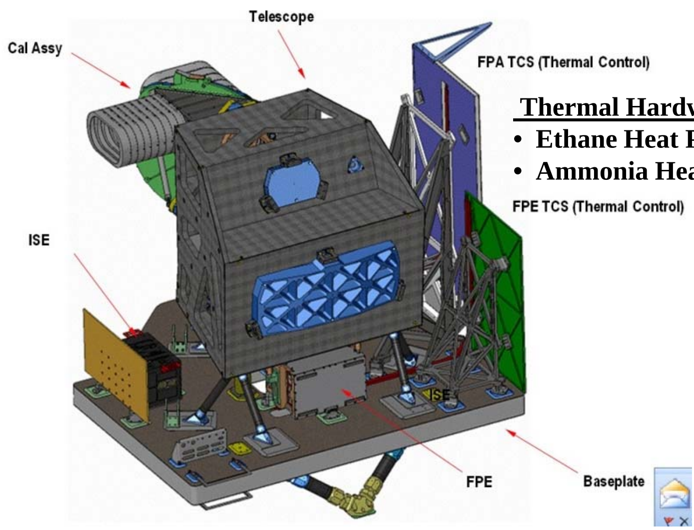
The adequacy of the thermal design and the capability of the thermal control system will be verified under simulated on-orbit worst case hot and worst case cold environments, and at least one other condition to be selected by the Contractor and approved by the GSFC LDCM Project.
Consideration will be given for testing an "off nominal" case such as a safehold or a survival mode.

LEVR-2134 The test environments shall bound the worst hot and cold flight environments such that the test results directly validate the adequacy of the thermal design.

An additional objective of the test is to verify and correlate the thermal model so it can be used to predict the behavior of the observatory under future non-tested conditions and/or flight conditions. It is preferable that the thermal balance test precede the thermal vacuum test so that the results of the balance test can be used to establish the temperature goals for the thermal vacuum test.

Landsat 8 Instrument Suite

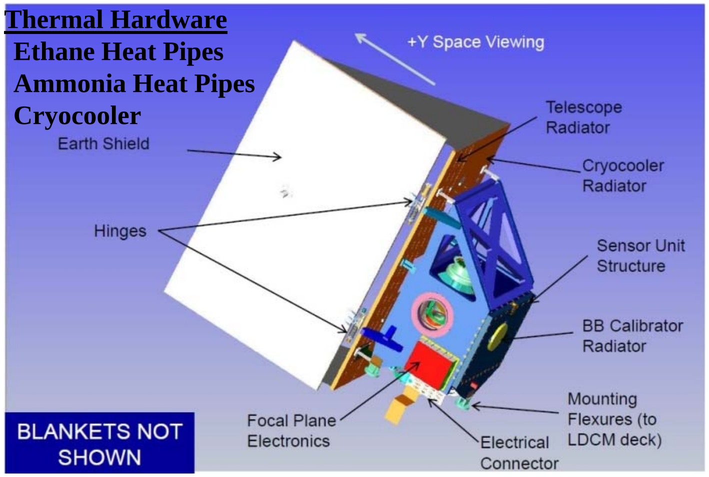
Operational Land Imager (OLI)



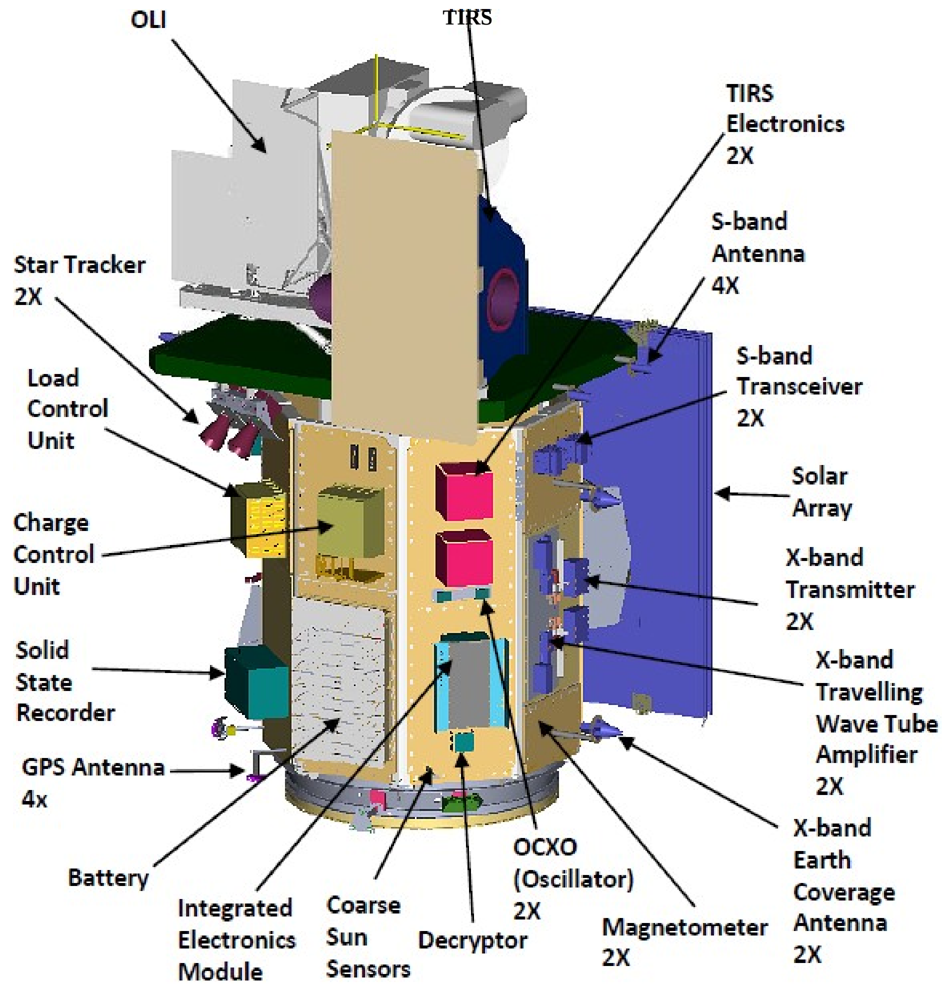
Thermal Hardware
- **Ethane Heat Pipes**
- **Ammonia Heat Pipes**

Thermal Infrared Sensor (TIRS)

Thermal Hardware
- **Ethane Heat Pipes**
- **Ammonia Heat Pipes**
- **Cryocooler**

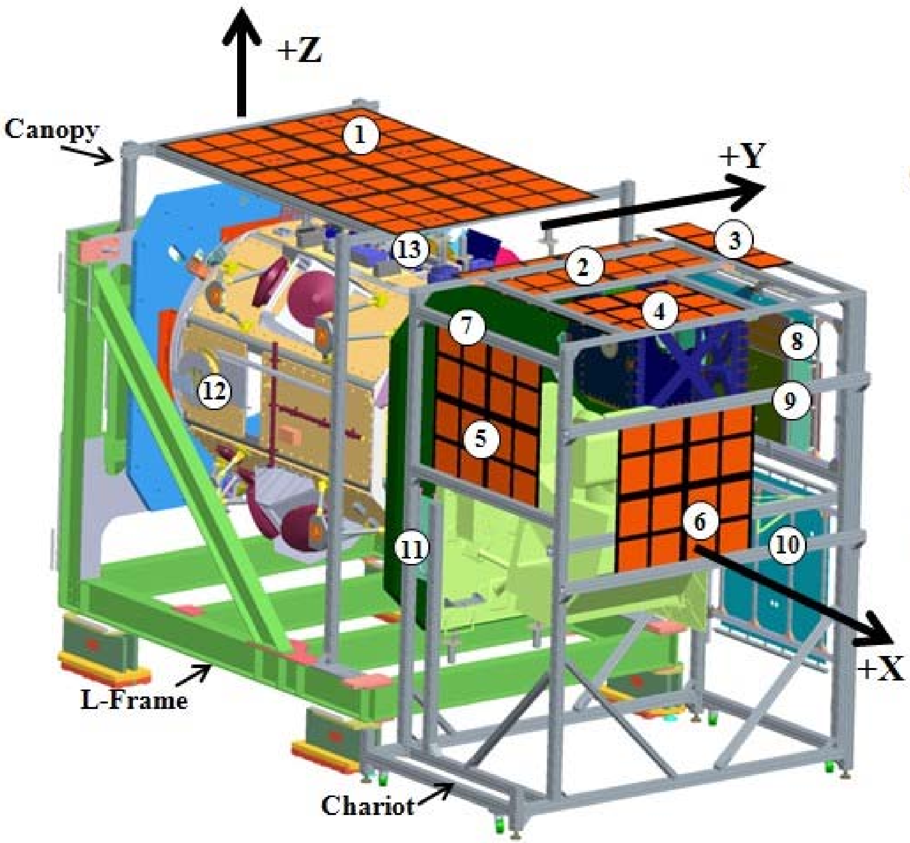


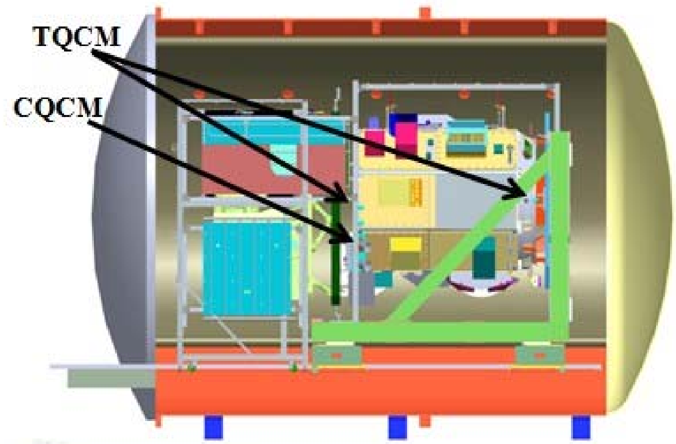
Spacecraft Bus



Thermal Hardware
Ammonia Heat Pipes

Thermal Vacuum Test Set-Up

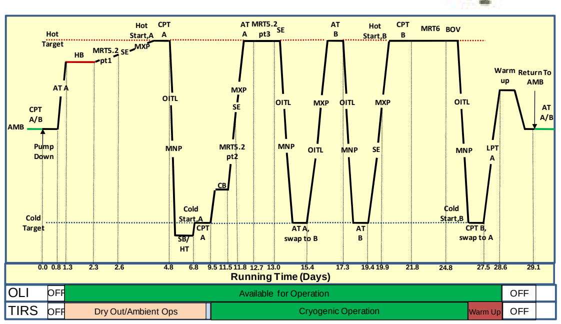




Legend	
1	SC +Z IR Plate
2	TIRS +Z IR Plate
3	TIRS Hinge Line IR Plate
4	OLI +Z Snorkel IR Plate
5	OLI -Y Snorkel IR Plate
6	OLI +X IR Plate
7	Deck Blanket Heater
8	TIRS Telescope Radiator LN_2 Plate
9	TIRS Cryocooler Radiator LN_2 Plate
10	OLI FPA/FPE Radiator LN_2 Plate
11	OLI ISE Radiator LN_2 Plate
12	Contamination LN_2 Plate
13	X-Band Load GN_2 Plates

TVAC Configuration Summary

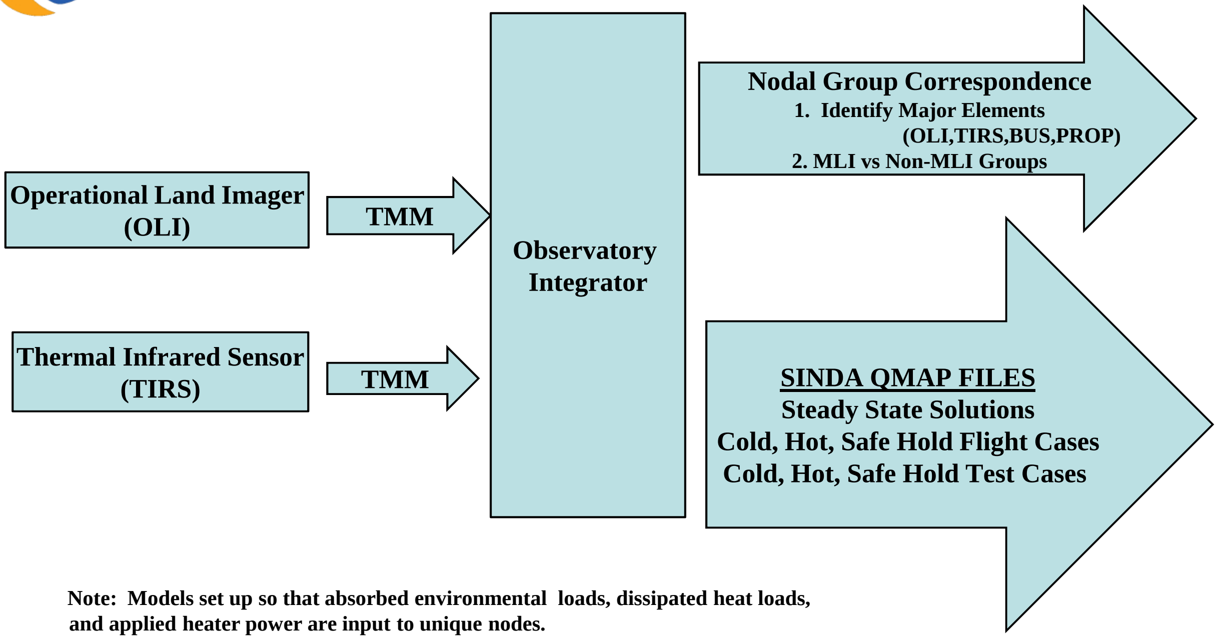
- # T/Cs = 426
- # Test heater zones = 47
- LN2 Zones = 6
- GN2 Zones = 1
- QCMs
  - 2 TQCMs
  - 1 CQCM



Methodology Objectives

- Systematic process that inputs raw data directly from flight and TVAC models that generates quantitative measure of how the two environments compare.
- Create process that forces a detailed look at the model output to flush out analytical errors prior to test initiation.
- Generate summary output that facilitates communication to project management of environment comparison analyses results.

Methodology Overview



A) Verify steady state solution

B) Calculate Group to Group Energy Balances

C) Flight Versus TVAC Model Group Comparison

D) Flight vs TVAC Power Dissipation Comparison

E) Flight vs TVAC Environment Comparison

Note: Models set up so that absorbed environmental loads, dissipated heat loads, and applied heater power are input to unique nodes.

For each case set pair (Flight /TVAC) :

a) Assume groups coupled to space sink in the flight case have environmental inputs.
b) Calculate QNet Flight (QAbsEnv-Qspace) for each of these groups
c) Calculate QSink TVAC for each of these groups
d) Compare QNet to QSink
e) Sum heat flow differences to generate Flight to TVAC Comparison metric (with/without MLI) for each case set.

Calculate Group To Group Energy Balances

Program input : Group Nodal Correspondence
SINDA QMAP Data Dump

```
b20c.qmap
Temp=C
Power=WATTS
Area=in**2
Boltz=3.661e-11
Output=QMAP
End of Data
SUBMODEL BUS
99999 $ BUS Space Node
800010,800030,800050,800060,800080,800100,800110,800120,800130,800140,800150 $ BUS PZ Panel By AMT Radiating Surfaces
800011,800021,800041,800051,800061,800101,800111,800121,800131,800141,800151 $ BUS PZ Panel MLI
80001-80015 $ BUS PZ PANEL PX COMPOSITE PANEL
80016 $ BUS PX STRINGER
35000 $ BUS AMT 1 radiator
35001 $ BUS AMT 1 mli
3500 $ BUS AMT 1
35010 $ BUS AMT 2 radiator
35011 $ BUS AMT 2 mli
3501 $ BUS AMT 2
35220 $ BUS PZ Panel XBND Ant 1 radiating surface
35221,35231 $ BUS XBND Ant 1 mli
3522,3523 $ BUS XBND Ant 1
801020,801030,801040,801050,801060,801070,801080 $ BUS PZ Panel Mid, Xband/EPC radiating surfaces
801011,801021,801041,801061,801081,801091,801101,801111,801121 $ BUS PZ Panel Mid MLI
80101-80112 $ BUS PZ   PANEL MID (AL)
35201 $ BUS XBND TX 1 mli
3520 $ BUS XBND TX 1
35211 $ BUS XBND TX 2 mli
3521 $ BUS XBND TX 2
35301 $ BUS TWTA EPC 1 mli
3530 $ BUS TWTA EPC 1
35351 $ BUS TWTA EPC 2 mli
3535 $ BUS TWTA EPC 2
802010,802020,802030,802040,802050,802060 $ BUS PZ TWTA HP Panel Radiating Surfaces
35330,35380 $ BUS PZ Panel PX Composite
80201-80206 $ BUS PZ   PANEL MID HP COMM PANEL
35310, 35330 $ BUS TWTA 1 radiating surfaces
```

Corresponds to major element ID

MLI nodes in separate groups
Label 'MLI' included in Group Descriptor

Program Features

- **Validates nodal correspondence file**
  - **Verifies all nodes included in a group**
  - **Verifies no nodes included in two or more groups**
  - **Verifies boundary nodes are sole nodes in their respective groups.**
- **Calculates Group To Group Energy Balances including group to group FAE radiation couplings.**
- **Outputs .MAP file with all group to group energy balances.**

Output Example: Space Sink (Cold Ops Case)

Begin Processing Group 1 $ BUS Space Node 9/25/2012 12:38:09 AM
******************* 1 of 649 **
99999 $ BUS Space Avg Temp = -273.0 (-273.0 to -273.0)
99999
CAP = 0.000 Group FOM = 0.000
Heat Sources:
0 $ BUS Space Node 999
Linear Con duction:
QFlow Temp
QMAP C
Radiation Exchange: RadSum To Group: 116030.566489 IN**2

Group to group FAE radiation couplings

Listing ordered by heat flow

QFlow QMap	Temp C	Fae IN**2	Group Description
4624.55	22.5	16535	$ BUS SA PANEL 4 (FARTHEST FROM BUS) 2004
4615.41	22.7	16465	$ BUS SA PANEL 3 (MIDDLE PANEL 2) 2003
4604.81	23.3	16284	$ BUS SA PANEL 2 (MIDDLE PANEL 1) 2002
3258.61	16.2	11711	$ BUS SA PANEL 1 (CLOSEST TO BUS) 2001,2015
641.3412	-14.9	3935.26078	$ BUS Instrument Deck MLI 10511-11251
445.2307	-27.6	3316.8388	$ TIRS TIRS_ES Earth SHIELD 300-359 300-359
355.5366	-14.7	2238.07	$ BUS BOTTOM CLOSEOUT BLANKET EXTERNAL MLI 13091,13211-13281
346.603	50	867.98	$ BUS SA PANEL 1 MLI 20011
249.0403	-25.5	1720.32	$ BUS LV ADAPTER MLI 13011-13081
235.0502	-37.2	2024.681	$ OLI Cal Assy MLI (ext) 5951-5962
203.232	-27	1551.2575	$ TIRS TIRS_ES MLI 403-438,450-454,470-474 403-438,450-454,470-474
203.098	-0.4	1002	$ BUS MLI - NY PANEL PX 860001
187.623	2.8	884.6	$ BUS RW 3,4 MLI 201
181.239	-1	902.56	$ BUS PZNY RWA MLI 301
177.5098	-5.8	956.937	$ BUS Battery Radiator 321001-321024
156.3357	-39	1818.411	$ OLI CO MLI Skirt (ext) 8940-8949
130.802	-9.8	742.99	$ BUS MLI - NZ PANEL PX 840001
125.6774	-16.4	778.715	$ BUS TOP CLOSEOUT MLI OUTER 16011,16021,16031,16041,16051,16061,16071,16081
101.342	-18.6	659.19	$ BUS RW 1,2 MLI 101
100.114	-0.1	492	$ BUS MLI - NYNZ PANEL NX 851001
99.5171	-12.2	586.08	$ BUS MLI - PZNY PANEL NX 871001
99.0873	-19.1	834.326	$ OLI PX Baseplate MLI 13701-13714
98.8766	0.7	480.48	$ BUS MLI - NYNZ PANEL PX 850001
92.3374	-26	591.6734	$ TIRS Closeout MLI [HSG_MLI] 4201-4222,14201-14222,24202,24210,104253-104254,10428
87.8795	-1.7	442.54	$ BUS SSR NZPY PANEL NX Radiating Surface 831010
87.6418	-17.5	565.49688	$ TIRS Structure, -Y/+X Slanted Truss [HSG_MLI_MINUSY] 14121-14134,14181-14194
87.3406	-9.9	496.99	$ BUS MLI - PZNY PANEL PX 870001
85.6012	-29.4	662.75	$ BUS PZPY PANEL NX MLI 811001
84.8902	-14.4	517.12065	$ TIRS MLI on +Z [HSG_MLI_PLUSZ] 4241,14321-14332,24241
84.6184	-33.6	702.19	$ BUS SSR mli 31101
76.5692	-33.3	715.506	$ OLI Ext MLI Skirt 6191-6196
70.3451	-24.7	516.76	$ OLI FPA Truss MLI 9390-9393
65.509	-13	390.75	$ BUS PZNY RWA Radiator 300
63.7555	-7.3	348.91	$ BUS MLI - NZ PANEL NX 841001
62.7182	-6	339.2896	$ BUS PZPY Panel Radiating surfaces 810010,810030,810060,810070,810080,810090,810120,
59.4747	-44.4	664.6252	$ OLI MLI BP Edge MLI 13940-13950
59.4182	-14.4	361.94	$ BUS PZ Panel NX MLI 803011
56.9927	3.7	265.352	$ BUS SA LAUNCH SUPPORT, NZNY NX MLI 24101,24111,24121,24131
55.1849	-33.8	459.22	$ BUS IEM MLI 31001
54.9987	29.8	178.31	$ BUS SIRU Radiator 101
54.2051	-8.9	283.019	$ BUS IEM radiating surfaces 31000,31010,31020

- **Landsat Observatory Flight Model included 649 groups**
- **Energy balance similar to shown calculated for each group**
- **These data used as basis to compare flight versus test thermal environments.**

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0.0012	-40.5	0.01091	$	TIRS Telescope Isolation System(TIS), Mid Ring, Telescope Shield I/F, [TELEALR1] 1761,1762
0.001	-87.1	0.02163	$	TIRS Telescope MISC PARTS, RETAINERS, SPRINGS, ETC. [LENSAS34] 1751-1757
0.0009	-23	0.00625	$	TIRS OSC Lid Man Hole Cover [ManHoleCoverMLI] 10808-10810,10836-10839,10850,20808-
0.0008	7.3	0.00355	$	OLI Quaternary Mirror MLI 11481
0.0008	-24.9	0.00581	$	TIRS CRYOCOOLER MOUNT CCM (Keel) (Key Group) [KEELRED] 931-985
0.0007	-25.4	0.00493	$	TIRS MLI Tunnel [BellowsMLI] 10701-10711,20707,20711
0.0007	23.3	0.00238	$	OLI Cal Assy Stim Lamp-2 7792
0.0006	17.8	0.00225	$	OLI Secondary Mirror Silver 11201
0.0006	-17.2	0.00377	$	TIRS Foot, -Y MLI [HSG_FT3_MLI] 4367,14367
0.0005	-111.8	0.02020	$	TIRS APG BAR Telescope Link [TelescopeLink] 801-807,823-835,840-847
0.0004	9.2	0.00179	$	OLI Cal Assy Shutter Wheel Motor &Mech 7600
0.0004	54.9	0.00089	$	OLI Heater Plate 6 4806
0.0004	39.9	0.00104	$	OLI Heater Plate 5 4805
0.0003	-19.8	0.00203	$	TIRS Foot, +Z MLI [HSG_FT1_MLI] 4387,14387
0.0003	-86.7	0.00655	$	TIRS Telescope Lens 3 [LENS3] 1736
0.0003	-77.8	0.00485	$	TIRS 1 Layer Telescope Blanket [TELEMLI] 1783-1787
0.0003	-86.9	0.00599	$	TIRS Telescope Aft Barrel TCB Sensor Htr Zone 1 (Key Group)[TBODY3] 1721-1726

GROUP SUMMARY:

	QMAP
Heat Sources :	0
Linear Conduction :	0
Radiation Exchange :	25050.94
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Heat Flow Balance :	25050.94

Flight Versus TVAC Model Group Comparison

- Verify groups included in each model are consistent with test configuration.
- Rigorous check performed to identify which sub-models included in each model.

Sample Output

SUMMARY COMPARISON - Cycle Thru TVAC - Compare to Flight

17 Groups Not Coupled In TVAC File

1 Space Node
5 BUS SA PANEL 1 MLI
6 BUS SA PANEL 1 (CLOSEST TO BUS)
7 BUS SA PANEL 2 (MIDDLE PANEL 1)
8 BUS SA PANEL 3 (MIDDLE PANEL 2)
9 BUS SA PANEL 4 (FARTHEST FROM BUS)
10 BUS SA DAMPER 1 (CLOSEST TO BUS)
11 BUS SA DAMPER 2 (FARTHEST FROM BUS)
12 SADA Wire bundle
13 TIRS ES/SB EARTHSHIELD Upper ES to Wing Closeout
14 TIRS ES/SB EARTHSHIELD Upper Wing
15 TIRS ES/SB EARTHSHIELD Lower ES to Wing Closeout
16 TIRS ES/SB EARTHSHIELD Lower Wing
17 TIRS Strongback (Key Group)

27 Groups In TVAC File Not In Flight File

1 TVAC CHAMBER END - MAN DOOR
2 TVAC L-FRAME
3 TVAC MLI - L-FRAME
4 TVAC L-FRAME ADAPTOR PLATE
5 TVAC MLI L-FRAME ADAPTOR PLATE
6 TVAC STANCHIONS
.
. Output removed
.
22 TVAC TIRS TELE RAD COLD PLATE BACKSIDE MLI
23 TVAC PZ BUS IR PLATE
24 TVAC PZ TIRS IR PLATE
25 TVAC OLI PZ SNORKEL SHOWER CAP
26 TVAC OLI PY SNORKEL SHOWER CAP
27 TVAC TIRS NADIR SHOWER CAP

SUMMARY COMPARISON - Cycle Thru Flight QMAP - Compare To TVAC

4 Groups Not Coupled In Flight File

1 BUS OCXO 1 radiator
2 BUS OCXO 2 radiator
3 BUS DECRYPTOR radiator
4 OLI SPACE NODE

3 Groups In Flt File Not In TVAC File

1 BUS SEP RING
2 TIRS_ES Earth SHIELD 300-359
3 TIRS_ES MLI 403-474

Note:
Due to rules associated with how SINDA generates QMAP files, nodes not included in the model could show up in the QMAP but not be coupled to anything.

Flight vs TVAC Power Dissipation Comparison

- Critical to evaluate power dissipation assumptions embedded in flight and TVAC models for consistency.
- In practice, with hardware as complex as an Observatory, it is not a simple matter to match powers exactly though that assumption is implicit in the test verification methodology.
- Process To Evaluate Power Dissipation Assumption
  - Simple program inputs a power dissipation specification file that lists all groups with power dissipation.
  - Program cycles through MAP files, identifies all groups with non-zero power dissipation, and verifies that specification file has correctly identified all groups.
  - First iterate through TVAC files and then flight files.

Flight vs TVAC Power Dissipation Comparison

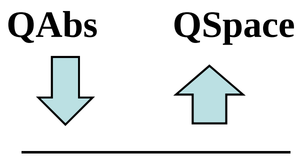
	Hot Operations		Cold Operations		Safehold	
	Flight	TVAC	Flight	TVAC	Flight	TVAC
	Watts	Watts	Watts	Watts	Watts	Watts
Spacecraft Power	703.9	777.8	520.3	582.3	319.2	336.2
OLI Dissipated Power	68.4	68.4	68.4	68.4	41.9	48.7
TIRS Sensor Dissipated Power	88.7	0.0	67.5	67.5	0.0	0.0
TIRS MEB Dissipated Power	71.0	71.0	40.0	40.0	0.0	0.0
TIRS CCE Dissipated Power	53.9	13.0	23.0	23.0	0.0	0.0
Spacecraft Heaters	34.3	120.7	194.3	256.3	304.2	531.8
Propulsion System	1.5	21.5	56.6	44.4	91.1	45.9
OLI Heaters	37.4	64.9	61.6	78.5	1.6	29.7
	1059.1	1137.3	1031.7	1160.4	757.7	992.3

		Hot Operations		Cold Operations		Safehold	
	NODE	Flight	TVAC	Flight	TVAC	Flight	TVAC
OLI DISSIPATED POWER		Watts	Watts	Watts	Watts	Watts	Watts
OLI FPA ROIC POWER	OLI.9000	1.4	1.4	1.4	1.4	0	0
OLI FPA BOX	OLI.8000	40.5	40.5	40.5	40.5	23.35	26.04
OLI FPA ANALOG CARD	OLI.8007	4.5	4.5	4.5	4.5	0	0
OLI ISE	OLI.6700	22	22	22	22	18.51	22.7
		68.4	68.4	68.4	68.4	41.9	48.7
TIRS SENSOR DISSIPATED POWER							
TIRS FPE Boards	TIRS.69,70	4.2	0	3.35	3.35	0	0
TIRS CRYOCOOLER TMU Compressor	TIRS.904,907,9	46.26	0	34.65	34.65	0	0
TIRS CRYOCOOLER TMU Displacer	TIRS.922,925,9	35.74	0	27.35	27.35	0	0
TIRS SSM Encoder Remode Electronics	TIRS.1065	0.7	0	0.65	0.65	0	0
TIRS SSM Encoder Read Head	TIRS.1072,1075	1.04	0	0.98	0.98	0	0
TIRS SSM Motor	TIRS.1232,1233	0.01	0	0.01	0.01	0	0
TIRS FPA QWIP Detector	TIRS.1897-1899	0.41	0	0.41	0.41	0	0
TIRS FPW1 I^2R Heating	TIRS.1921-1924	0.3	0	0.1	0.1	0	0
		88.7	0	67.5	67.5	0	0

Flight vs Test Environmental Comparison

Key Definitions & Nomenclature

Flight Thermal Environment

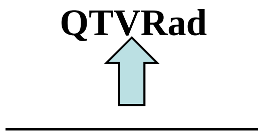


For each group with view to space:

QNet = QAbs – QSpace

Where: QNet = Flight Environment
QAbs = Absorbed heat load from solar/earth heat sources
QSpace = Heat radiated to space sink

TVAC Thermal Environment



For each group with view to chamber/cold sink:

QTVRad = Heat radiated to TVAC Hardware (Chamber, Cold plates, etc.)

Flight/TVAC Comparison

Delta = Heat difference for a particular group between flight and TVAC
Delta=QTVRad – QNet

NetTot = Cumulated delta sum for each major Observatory hardware element.
(OLI, TIRS, BUS, PROP)

Note: Test article conductively isolated from TVAC test support structure and guarded with zero-Q heaters.

Flight vs Test Environmental Comparison

Cold Ops Output For BUS:

COMPONENT DESCRIPTION	FAE Spc	TAvg	QAbsEnv	QSpace	QNet	TSnk	TVSnk	Temp	QTVRad	EnvTestQ	DELTA	NetTot	NetXMLI	TEST
	in**2	C	Watts	Watts	Watts	C	(C)	(C)	(W)	(W)	(W)	(W)	(W)	COND
BUS SA PANEL 4 (FARTHEST FROM BUS) 20	16535	22.5	4628.91	4624.55	4.36	22.4	GROUP NOT	COUPLED	IN TVAC MODEL	0				
BUS SA PANEL 3 (MIDDLE PANEL 2) 2003	16465	22.7	4625.63	4615.41	10.22	22.6	GROUP NOT	COUPLED	IN TVAC MODEL	0				
BUS SA PANEL 2 (MIDDLE PANEL 1) 2002	16284	23.3	4633.64	4604.81	28.83	23.2	GROUP NOT	COUPLED	IN TVAC MODEL	0				
BUS SA PANEL 1 (CLOSEST TO BUS) 2001,2	11711	16.2	3310.52	3258.61	51.91	21.9	GROUP NOT	COUPLED	IN TVAC MODEL	0				
BUS Instrument Deck MLI 10511-11251	3935.3	-14.9	645.96	641.34	4.61	-13	-26.5	-34	-39.47	0	-44.08	-44.08	0	COLDER
BUS BOTTOM CLOSEOUT BLANKET EXTERN	2238.1	-14.7	339.73	355.54	-15.81	-16.4	-61.9	-60.3	-19.33	0	-3.52	-47.6	0	COLDER
BUS SA PANEL 1 MLI 20011	868	50	410.21	346.6	63.61	49.5	GROUP NOT	COUPLED	IN TVAC MODEL	0				
BUS LV ADAPTER MLI 13011-13081	1720.3	-25.5	233.7	249.04	-15.34	-22.7	-58.9	-59.2	-19.47	0	-4.13	-51.73	0	COLDER
BUS MLI - NY PANEL PX 860001	1002	-0.4	171.63	203.1	-31.47	-1.2	-69.9	-70.1	-10.21	0	21.26	-30.47	0	WARMER
BUS RW 3,4 MLI 201	884.6	2.8	176.85	187.62	-10.78	2	-65.8	-66.8	-10.74	0	0.04	-30.43	0	WARMER
BUS PZNY RWA MLI 301	902.6	-1	170.7	181.24	-10.54	-1.6	-62.4	-62.5	-10.2	0	0.34	-30.09	0	WARMER
BUS Battery Radiator 321001-321024	956.9	-5.8	32.02	177.51	-145.49	-97.9	-62.2	-2	-107.48	0	38.01	7.92	38.01	WARMER
BUS MLI - NZ PANEL PX 840001	743	-9.8	129.07	130.8	-1.74	-10.4	-63.5	-65.9	-10.14	0	-8.4	-0.48	38.01	COLDER
BUS TOP CLOSEOUT MLI OUTER 16011,16	778.7	-16.4	111.86	125.68	-13.82	-17.5	-51.3	-52.2	-15.53	0	-1.71	-2.19	38.01	COLDER
BUS RW 1,2 MLI 101	659.2	-18.6	97.94	101.34	-3.4	-18.8	-64.5	-65.5	-8.91	0	-5.51	-7.7	38.01	COLDER
BUS MLI - NYNZ PANEL NX 851001	492	-0.1	97.63	100.11	-2.48	-0.2	-66.8	-67.1	-6.19	0	-3.71	-11.41	38.01	COLDER
BUS MLI - PZNY PANEL NX 871001	586.1	-12.2	90.69	99.52	-8.83	-12.3	-59.1	-59	-2.55	0	6.28	-5.13	38.01	WARMER
BUS MLI - NYNZ PANEL PX 850001	480.5	0.7	96.4	98.88	-2.47	-0.5	-65.7	-67.9	-5.84	0	-3.37	-8.5	38.01	COLDER
BUS SSR NZPY PANEL NX Radiating Surface	442.5	-1.7	5.45	87.88	-82.43	-102.1	-66.6	1.5	-57.56	0	24.87	16.37	62.88	WARMER

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COMPONENT DESCRIPTION	FAE Spc	TAvg	QAbsEnv	QSpace	QNet	TSnk	TVSnk	Temp	QTVRad	EnvTestQ	DELTA	NetTot	NetXMLI	TEST COND
BUS PZ Panel XBND Ant 2 radiating surface	34.8	-7.9	6.29	6.3	-0.01	-8.4	-43.6	-24.6	-1.22	0	-1.21	-61.75	54.14	COLDER
BUS OCXO Mounting Plate radiating surface	28.9	3.3	2.73	6.17	-3.44	-40.8	-55.6	1.4	-3.7	0	-0.26	-62.01	53.88	COLDER
BUS PZ Panel XBND Ant 1 radiating surface	33	-7.5	6.1	6.01	0.08	-6.7	-39.3	-25.7	-0.92	0	-1	-63.01	52.88	COLDER
BUS SADA ELECTRONICS CONTROL UNIT (E	22.9	15.4	5.87	5.82	0.05	14.8	-67.7	-67.7	-0.31	0	-0.36	-63.37	52.88	COLDER
BUS GPS RX 2 Radiator 33010	20.1	-3.2	0.72	3.91	-3.19	-53.5	-62.1	-3.1	-2.57	0	0.62	-62.75	53.5	WARMER
BUS GPS RX 1 Radiator 33000	19.1	-0.5	0.66	3.87	-3.2	-49.2	-61.7	-3.5	-2.4	0	0.8	-61.95	54.3	WARMER
BUS PY Panel Battery Radiator 32110	34.3	-40.2	4.15	3.7	0.45	-39.1	-62	-62.8	-0.21	0	-0.66	-62.61	53.64	COLDER
BUS DECRYPTOR mli 35601	29.3	-32.8	3.25	3.58	-0.33	-32.8	-52.5	-52.4	-0.35	0	-0.02	-62.63	53.64	COLDER
BUS STAR CAMERA 1 BAFFLE 3120	23.6	-20.4	2.4	3.53	-1.12	-24.6	-44.6	-36.6	-1.32	0	-0.2	-62.83	53.44	COLDER
BUS PZ Panel PX Composite 35330,35380	20.2	-11.3	2.22	3.48	-1.26	-29.4	-30.5	-2.2	-1.74	0	-0.48	-63.31	52.96	COLDER
BUS NYNZ PANEL Radiating surface 85108	17.7	-6.5	0.75	3.28	-2.54	-40.3	-54.7	-9.4	-2.03	0	0.51	-62.8	53.47	WARMER
BUS GPS RX 1 mli 33001	15.7	0.1	3.09	3.2	-0.11	0	-65.9	-65.9	-0.19	0	-0.08	-62.88	53.47	COLDER
BUS Battery Radiator MLI 32101	65.1	-82	2.55	3.18	-0.63	-81.6	-71.9	-72.3	-0.44	0	0.19	-62.69	53.47	WARMER
BUS GPS RX 2 mli 33011	15	-0.6	3.03	3.02	0.01	-0.5	-65.1	-65.4	-0.2	0	-0.21	-62.9	53.47	COLDER
BUS STAR CAMERA 2 BAFFLE 3220	23.5	-30.8	1.96	2.97	-1.01	-35.7	-49.1	-41.2	-1.14	0	-0.13	-63.03	53.34	COLDER
BUS TAM 1 mli 33201	16.5	-15.1	2.62	2.67	-0.06	-15.1	-41	-41.1	-0.15	0	-0.09	-63.12	53.34	COLDER
BUS TAM 2 mli 33211	15.7	-13.2	2.62	2.63	0	-13.2	-41.3	-41.3	-0.14	0	-0.14	-63.26	53.34	COLDER

Equivalent Heat Sink calculated for reference.

Summation Columns

Process Products

FLIGHT VERSUS TEST ENVIRONMENT COMPARISON (TVAC_HTR_MOD-80CB) EXPRESSED AS FUNCTION OF ABSOLUTE HEAT FLOW						
	Hot Operations TVAC - Flight		Cold Operations TVAC - Flight		Safehold TVAC - Flight	
	RAD&MLI	RAD	RAD&MLI	RAD	RAD&MLI	RAD
	W	W	W	W	W	W
BUS	-45	82	-63	53	-133	21
OLI	28	6	48	11	17	0
TIRS	In Dry Out Mode		-23	6	-46	1
PROP	-8	-5	-7	-5	-3	2

FLIGHT VERSUS TEST ENVIRONMENT COMPARISON EXPRESSED AS PERCENTAGE OF TEST ARTICLE ENERGY BALANCE						
	Hot Operations TVAC - Flight		Cold Operations TVAC - Flight		Safehold TVAC - Flight	
	RAD&MLI	RAD	RAD&MLI	RAD	RAD&MLI	RAD
	%	%	%	%	%	%
BUS	-8	14	-19	2	-21	3
OLI	27	6	45	11	25	0
TIRS	In Dry Out Mode		-29	7	-73	2
PROP	-211	-132	-143	-102	-60	40

Note: Positive value means the test environment is warmer than the flight environment.

Summation columns for each major hardware element reported (BUS cold operations case comparison from previous page circled).

Set 10% energy balance threshold and claimed satisfaction of the test requirement for all components and cases except OLI (11%) in the cold operations case.

Issues Encountered

- "Bounding" thermal environment easier said than done …
  - Complicated hardware and many components with different temperature requirements.
- For Landsat-8, instrument survival temperature requirements limited how cold the chamber cold wall could be (ended up at -100 C for cold cases).
  - Understandable since cold case includes orbital environmental flux inputs whereas the chamber has none.
    - Heaters typically not installed at locations where the minimum cold case maintains temperatures above requirements.
    - In the chamber, these locations driven by the local (typically cold wall) thermal environment which can be colder.
    - Projects that include a bounding design case TVAC test requirement should consider designing for a colder test environment (flight and/or test heaters).

At The End Of The Day

- What is important …
  - Recognize shared goals to exercise models and perform a successful Observatory thermal vacuum test campaign.
  - Develop trust and maintain good communication between teams.
  - Minimize time required for Contractor to provide data.
  - Very helpful to quantitatively compare test and flight thermal environments so that the most sensible test conditions are applied.
  - Landsat-8 thermal vacuum test campaign ended up being very successful with few (if any) modeling issues identified.