Testing Example WIRE Spacecraft Test

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An Example – The WIRE Test

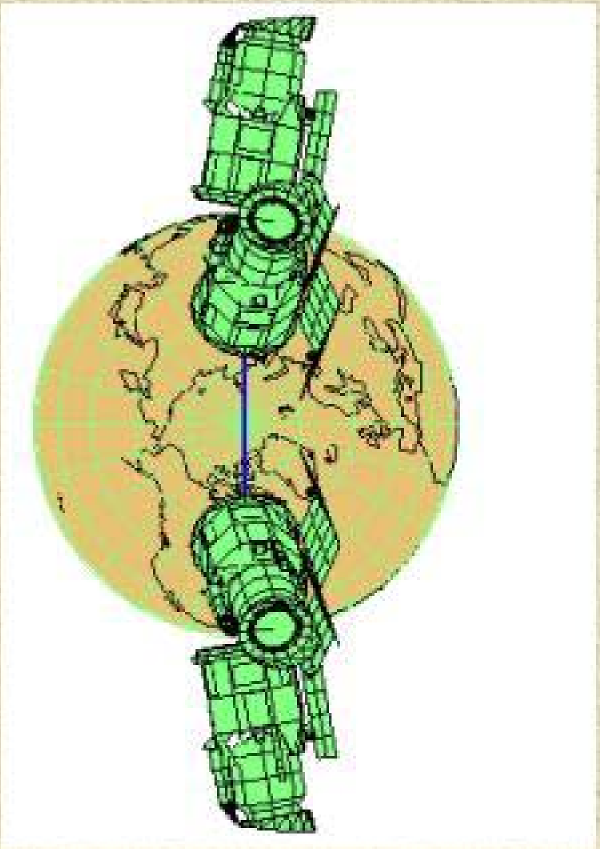
- In Spring of 1998 the Wide Field Infrared Explorer (WIRE) spacecraft was tested. This was part of the Small-Class Explorer (SMEX) missions done by NASA Goddard.
- WIRE was a 3-axis stabilized, momentum biased spacecraft with the instrument boresite primarily in the zenith direction. The baseline orbit was a 470 x 540 km sun synchronous orbit with a 6 PM crossing. It was designed to be a four month mission due to lifetime of the solid hydrogen dewar. It launched in February 1999.
- WIRE's mission was to detect galaxies with unusually high star formation rates "starburst galaxies". Unfortunately the instrument had a failure shortly after launch. However the thermal system performed flawlessly thus showing the success of the S/C thermal test program and design. The spacecraft was used for several years to train flight ops personnel.

Step 1: Understanding the Flight System

- Test Planning was begun late (~six month before test). Test objectives and configuration needed to be defined quickly in order to build GSE and develop procedures.
- SMEX Avionics Heritage from SWAS and TRACE.
- **The first step** was to review and understand the flight design, modes, requirements, and environment.
- WIRE's orbit resulted in a 60-90° Beta angle range.
- From February to September there was no eclipse

Orbital Summary

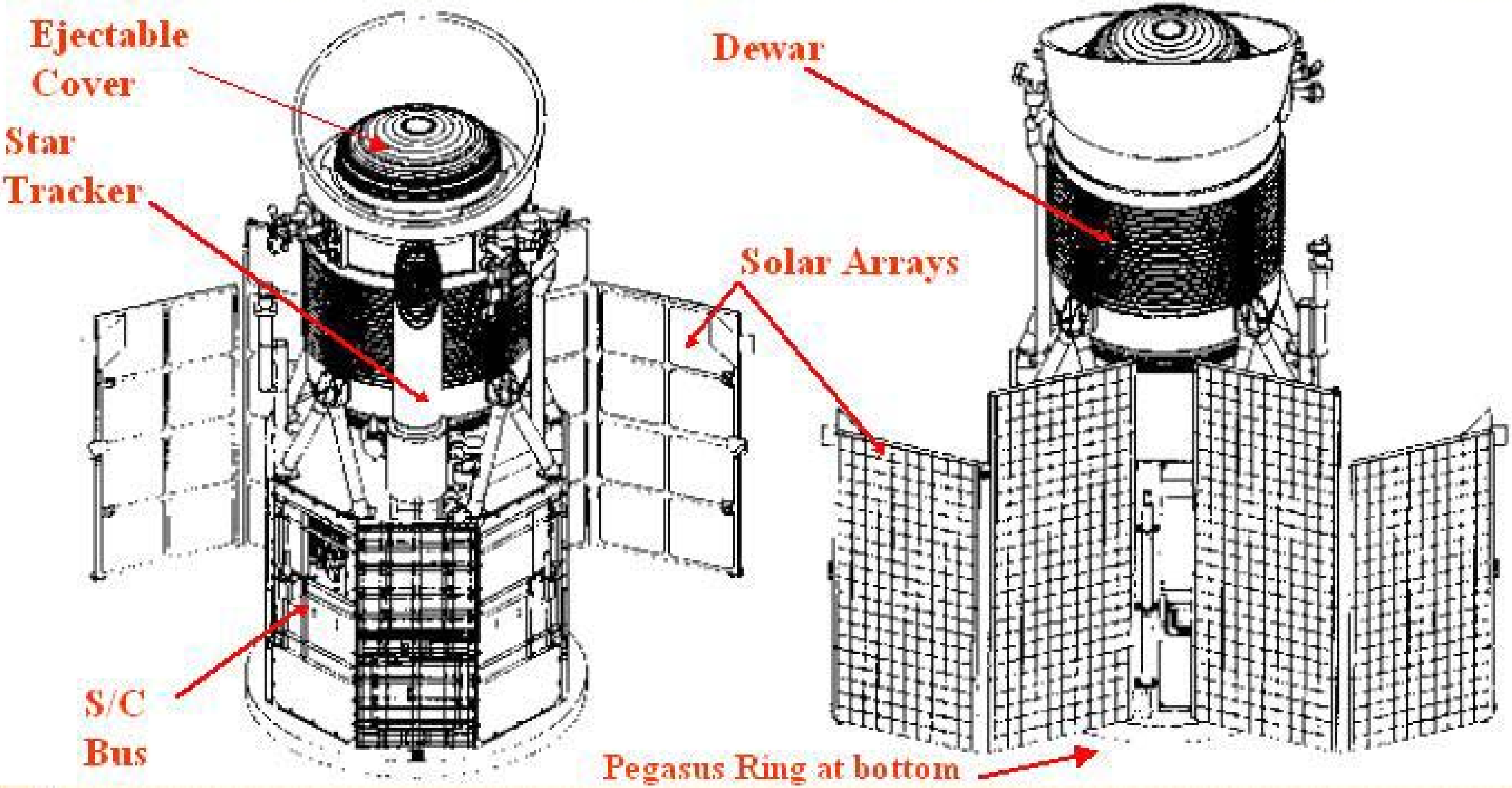
- **Hot Case - $\beta=90^o$, 30 degrees tilt back out-of-plane.**
- **Cold and Safehold Cases - $\beta=90^o$, 15 degree tilt towards sun.**
- **Environmental constants varied**



WIRE Temperature Limits

COMPONENT	OPERATING LIMITS (C)	SURVIVAL LIMITS (C)	MINIMUM TURN-ON (C)
SOLAR ARRAYS	-85/+95	-90/+100	NA
ACE	-10/+50	-20/+60	-20
BATTERY	0/+25	-10/30	0
SCS	-10/+40	-20/+50	-20
SPE	-10/+50	-20/+60	-20
S/A DAMPERS	-30/+50	-90/+100	NA
S/A HINGES	-30/+50	-90/+100	NA
TRANSPONDER	-10/+55	-20/+65	-20
OMNI ANTENNAS	-75/+80	-85/+90	NA
REACTION WHEELS	-10/+50	-20/+60	-20
SHUNT	-30/+50	-40/+60	-40
GYROS	+6/+48	-10/+50	0
MAGNETOMETER	-30/+50	-40/+60	-40
DSS HEAD	-20/+50	-30/+60	-30
DSSE	-20/+50	-30/+60	-30
CSS	-100/+70	-110/+80	-110
TORQUER BARS	-20/+60	-30/+70	-30
STAR TRACKER	-20/+40	-30/+50	-30
ESE	-10/+50	-20/+60	-20
EARTH SENSOR HEADS	-45/+80	-55	-45
WIE	-15/+50	-25/+60	-25
PYRO	-15/+50	-25/+60	-25

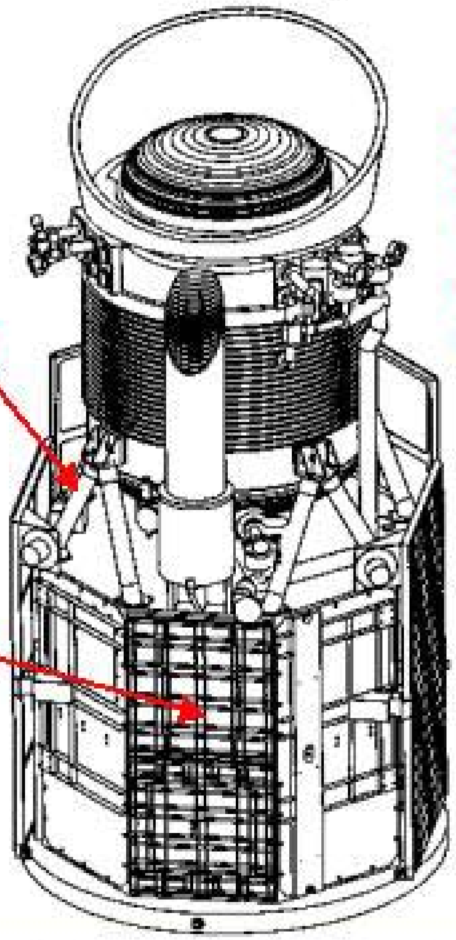
WIRE With Deployed Solar Arrays



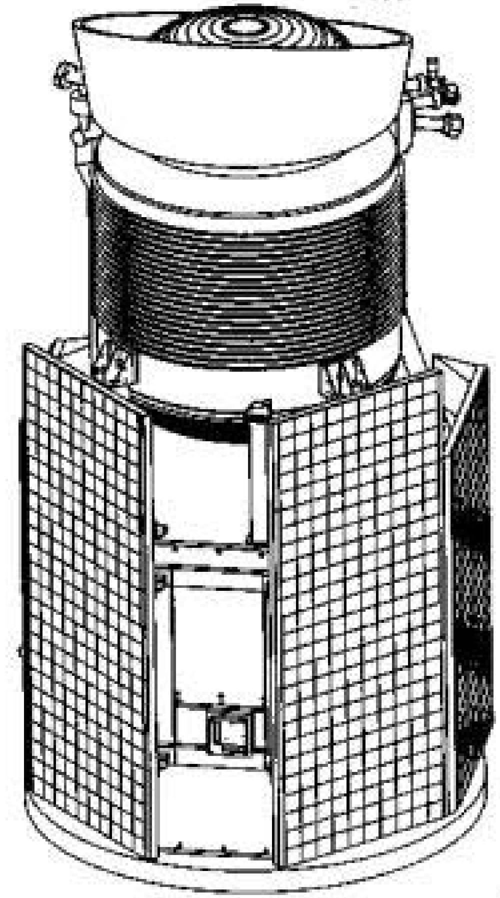
WIRE With Stowed Solar Arrays

Isolating Struts

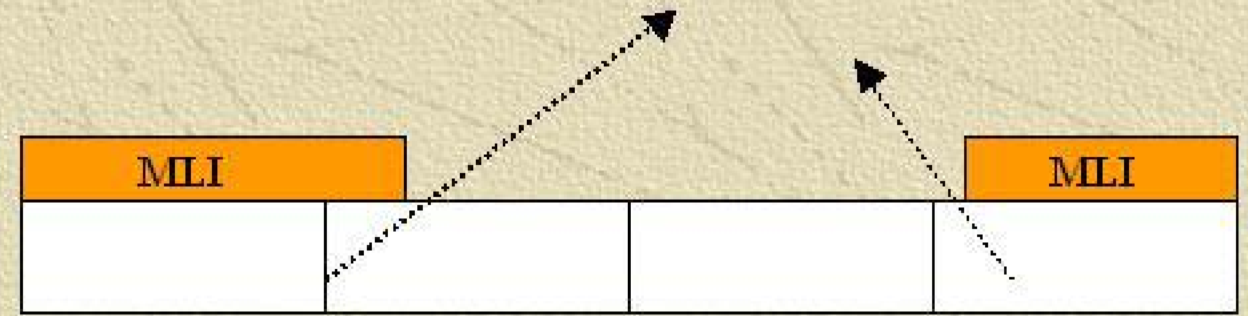
Radiators were waffled to enhance structural strength and radiation to space



Note: The S/C bus was a composite structure.

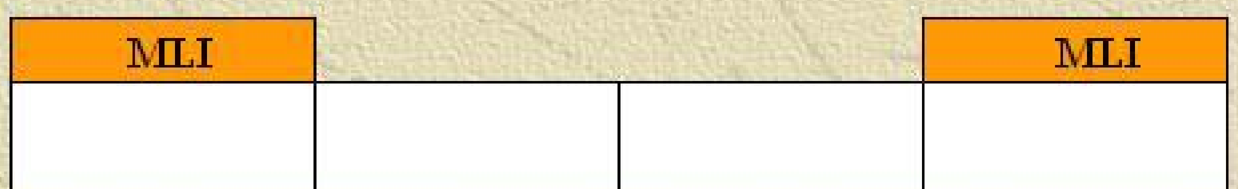


The Problem With "Waffles"

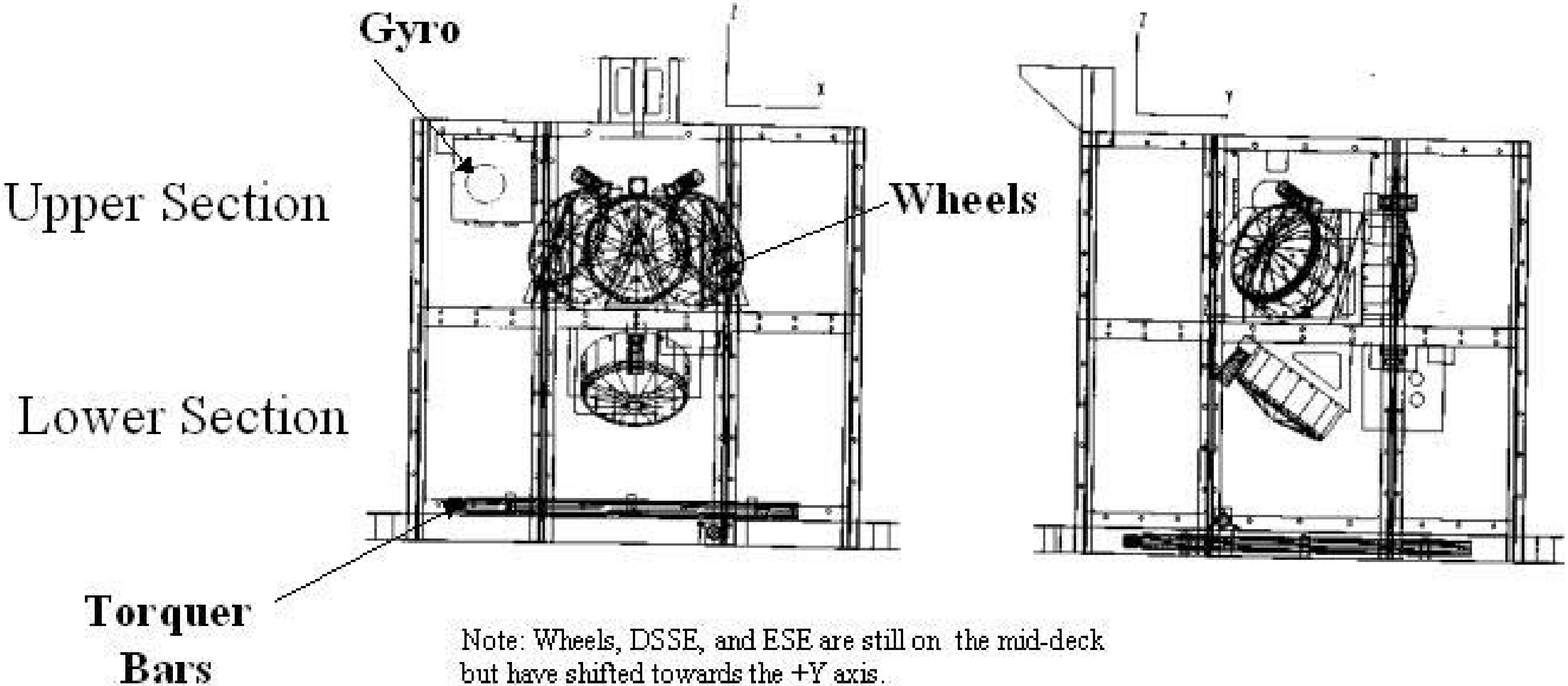


Area of Radiation greater than MLI opening. This is hard to quantify before testing

Solution: Design Radiators to end at Waffle walls and design clips to ensure good close-out



WIRE Components (Side Views)

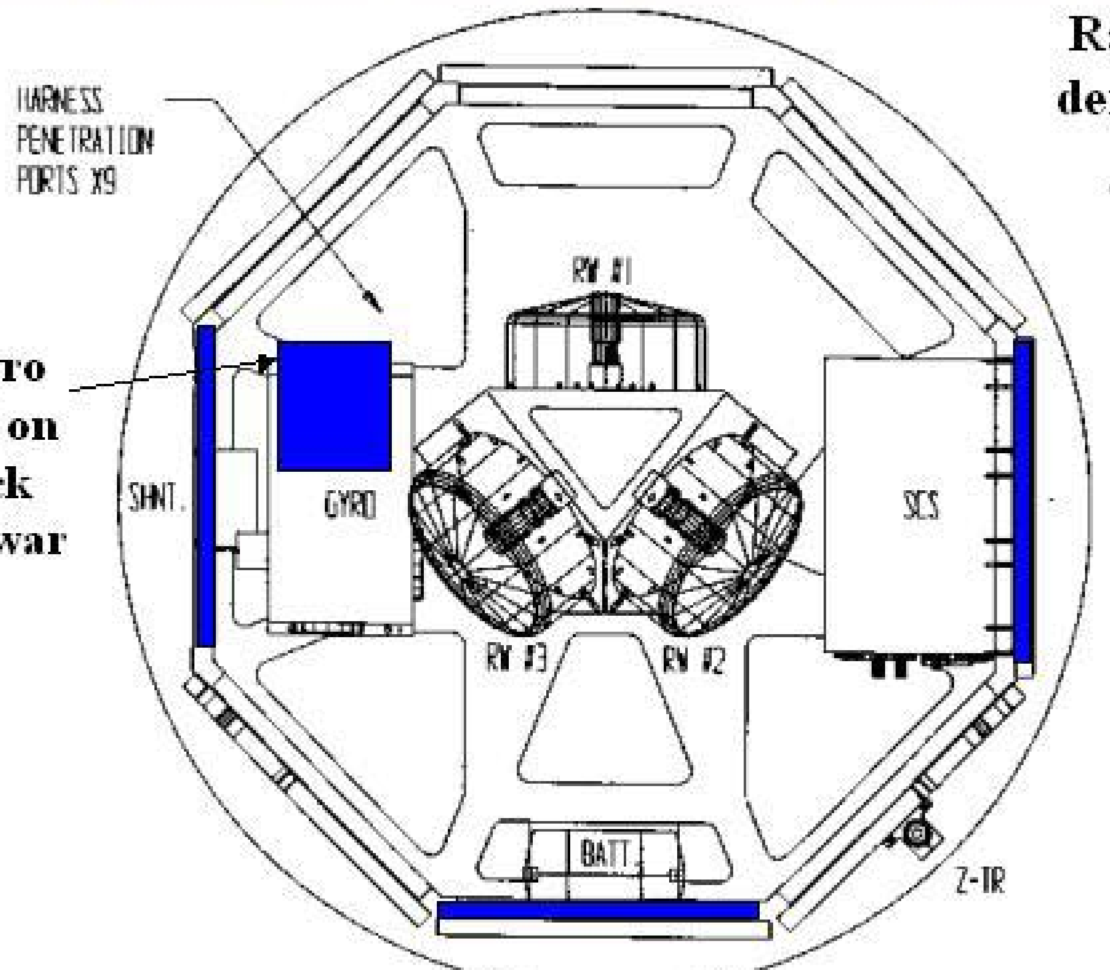


Note: Wheels, DSSE, and ESE are still on the mid-deck but have shifted towards the +Y axis.

Pyro is on the +X+Y+Z panel.

WIRE Components (Upper Section)

Radiators denoted by blue



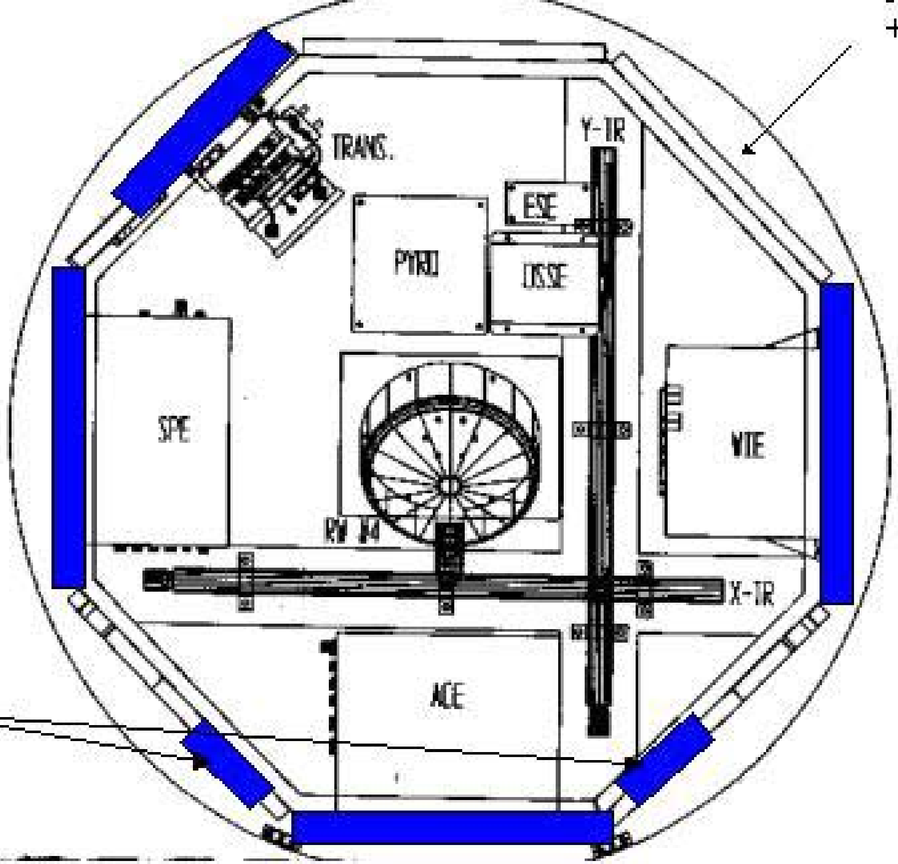
Note: Gyro Radiator on Top Deck under Dewar

Note: Wheels, DSSE, and ESE are still on the mid-deck but have shifted towards the +Y axis

WIRE Components (Lower Section)

Note: Wheels, DSSE, and ESE are still on the mid-deck but have shifted towards the +Y axis

PYRO is on the +Z+Y+X panel

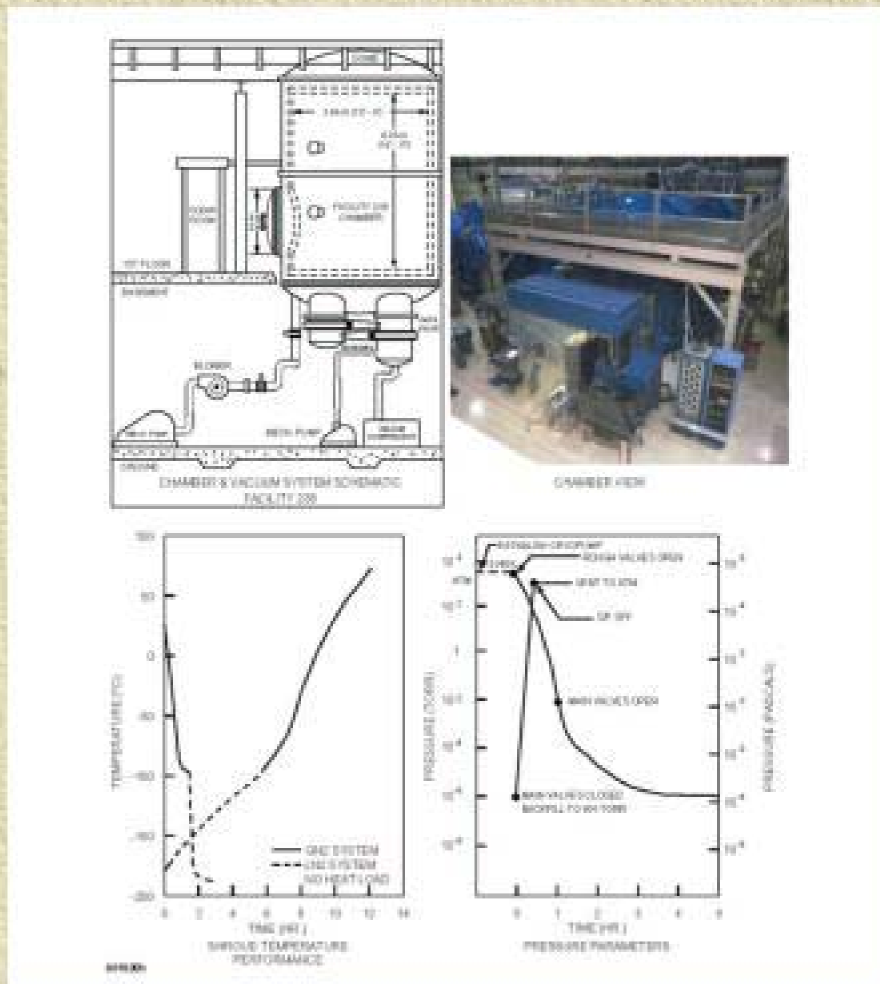


Radiators denoted by blue

Side radiators were originally centers but were moved to accommodate test set-up

+Y
+X

Chamber 238 "Big Blue"

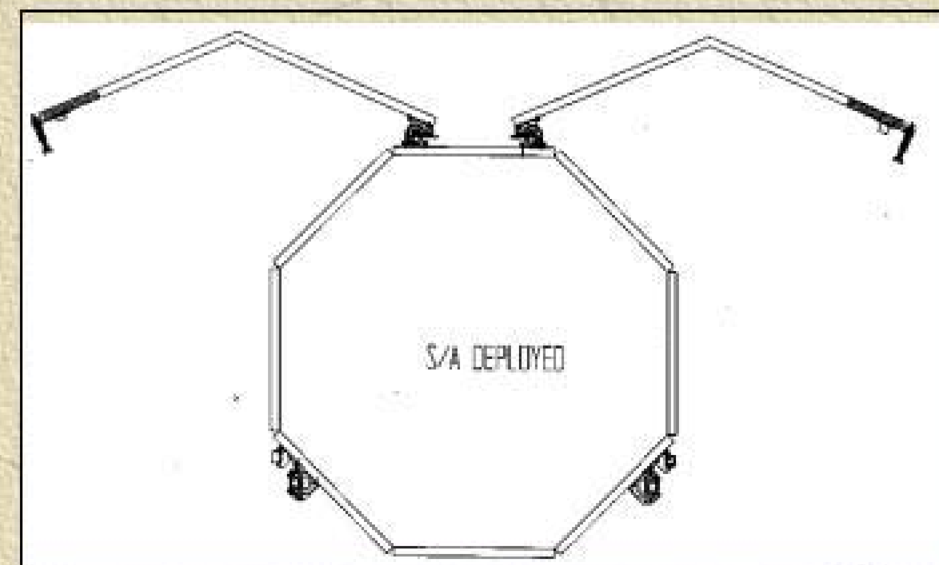


Chamber selected for size, capability, cost, and availability

Top View - WIRE Array Positions

The SMEX Project's philosophy was to do both a hot and cold deployment during the observatory level test.

Omni Antennas and CSSs mounted on Solar Arrays

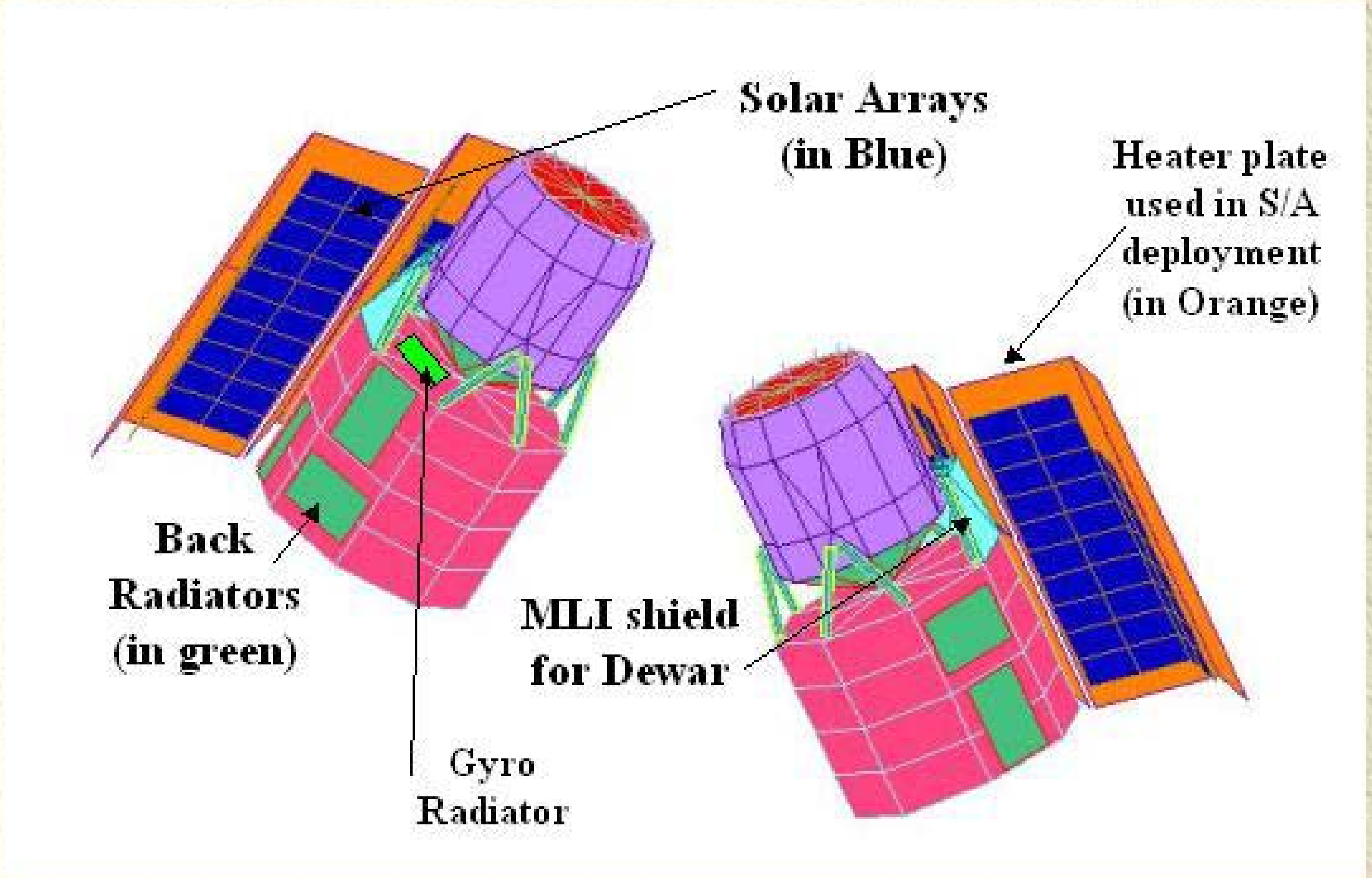


This was a key point in the test set-up because the radiators were partially blocked by the solar array in flight

Solar Arrays

- Chamber was not large enough to accommodate lamps (there was not enough time to order/calibrate lamps anyway).
- To get S/A (Solar Array) temperatures at flight levels for TB/TV test the ETU (Engineering Test Unit) Solar Arrays with test heaters mounted to backside were used. The flight deployment mechanisms and omni antennas were installed on the ETU solar arrays.
- Flight Solar Arrays cycled four more times in off-line test.
- Flight Solar Arrays, antennas, CSSs, deployment mechanisms installed prior to cold deployment test.
- Heater panels developed to control S/A temperatures for cold deployment.

Back Radiators and Solar Arrays



WIRE Heaters

Component	T'stat temp range		Power @ 26 V	
	Close (oC)	Open(oC)	(Watts)	Sensors
Operational Circuit:				
WIE	-11.7 +/- 2	-6.5 +/- 2	5.0	THMS#16, TC#9
ACE	-8 +/- 2	-2 +/- 2	7.0	THMS#5, TC#27
SPE	-8 +/- 2	-2 +/- 2	7.0	THMS#8, TC#46
SCS	-8 +/- 2	-2 +/- 2	5.0	THMS#11,TC#2
Battery	+2 +/- 2	+8 +/- 2	10.0	THMS#6,TC#22
Gyros	+6 +/- 2	+13 +/- 2	7.0	THMS#13,TC#59
Survival Circuit				
WIE	-11.7 +/- 2	-6.5 +/- 2	5.0	TC#14
ACE	-8 +/- 2	-2 +/- 2	7.0	TC#35
SPE	-8 +/- 2	-2 +/- 2	7.0	TC#52
SCS	-8 +/- 2	-2 +/- 2	5.0	TC#6
Battery	+2 +/- 2	+8 +/- 2	5.0	TC#26,THMS#7
Gyros	+2 +/- 2	+8 +/- 2	10.0	THMS#13,TC#59
Star Tracker	-18 +/- 1	-12 +/- 1		
S/A Damper Circuit				
S/A Damper (+X)	+2 +/- 2	+8 +/- 2	3.0	THMS#23
S/A Damper (-X)	+2 +/- 2	+8 +/- 2	3.0	THMS#23

Heaters Operate 25-35V with < 70% duty cycle. There was a goal to operated at 21 V without 100% duty cycle

Spacecraft bus non-redundant

WIRE Power Dissipation (Pretest)

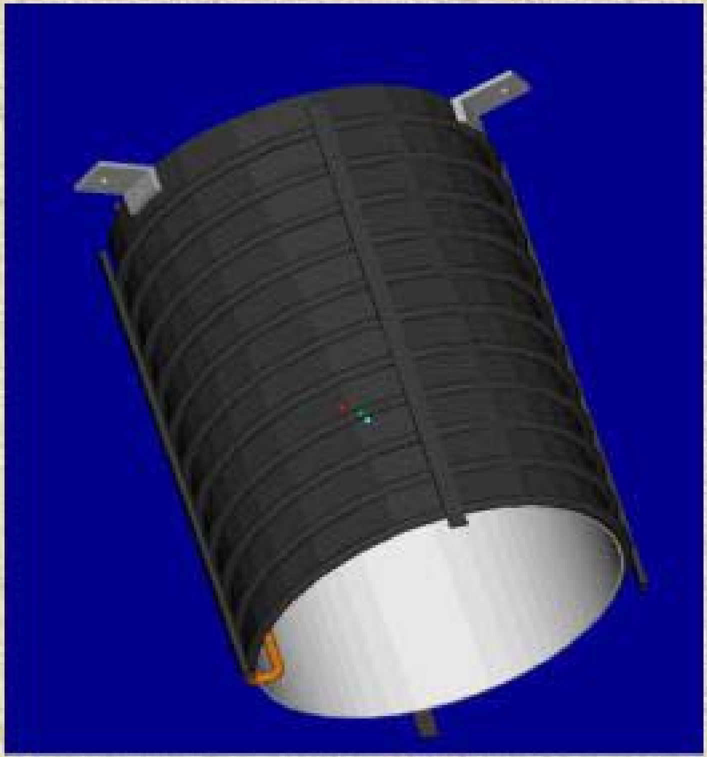
component description	Power (in Watts) Safehold	Cold Op	Hot Op	component description	Power (in Watts) Safehold	Cold Op	Hot Op
transponder	3.0	10.6	10.6	RW 1	2.5	4.0	4.0
SPE	8.7	13.2	13.2	RW 2	0.0	4.0	4.0
SCS	14.0	14.0	19.0	RW 3	0.0	4.0	4.0
battery	2.5	3.2	3.2	RW 4	0.0	4.0	4.0
gyro	0.0	15.0	5.0	torque rod X	2.5	0.1	0.1
Shunt	0.0	1.0	24.0	torque rod Z	2.5	0.1	0.1
ACE	18.0	33.8	33.8	torque rod Z	2.5	0.1	0.1
WIE	0.0	25.2	24.4	flight heater powers			
Startracker	0.0	11.0	12.0	SPE	12.2 W	1.3 W	0.0 W
Magnetometer	0.1	0.1	0.1	battery	11.6 W	10.4 W	0.0 W
DSS	0.1	0.1	0.1	WIE	10.0 W	0.0 W	0.0 W
DSSE	0.6	0.6	0.6	ACE	12.1 W	0.0 W	0.0 W
ESS +X	0.0	0.4	0.4	SCS	3.8 W	0.0 W	0.0 W
ESS -X	0.0	0.4	0.4	gyro	11.4 W	0.0 W	0.0 W
ESE (WAES)	0.0	2.1	2.1	Startracker	6.5 W	0.0 W	0.0 W
TOTALS	***57.0***	***146.8***	***165.0***				

Summary Step 1: Understanding The Flight System

- Identified radiator close-out issue.   Began detailed "waffle" study to define exact flight MLI pattern.
- Moved access panel radiators to avoid deployment test interference.
- Summarized operational scenarios, limits, and orbit.
- Began compiling component qualification data.
- Enhanced design of dewar MLI.
- Determined that Gyro radiator could not have a cryopanel because of space constraints.
- Defined solar array issues and plan.

Step 2: Define Goals, Test Flow, and Interface Issues

- **<u>The second step</u>** was to get representatives from each subsystem and the instrument together to define the test objectives. It was at this point that it was found that it could be detrimental to the instrument to be present during spacecraft testing. If the dewar seals failed then the instrument would be contaminated when the chamber was repressurized. Also a high-fidelity dewar simulator would allow thermal to conduct parametric studies.



Hardware #1 Priority Cylindrical Cold Plate Fabrication & Painting of Dewar Simulator

WIRE Test Objectives (System Level)

- Demonstrate that the observatory can operate satisfactorily in all functional modes for the mission, at temperatures 10° C beyond the hot and cold extremes expected on-orbit.
- Confirm thermal interface between the instrument simulator and spacecraft.
- Measure electronic component power dissipation at temperature extremes under normal operating conditions.
- Perform thermal cycling to satisfy GEVS requirements wherever possible.
- Demonstrate that a cold and hot power-off/power-on can be done.
- Show that the spacecraft will operate satisfactorily after exposure to survival temperatures.
- Perform an end-to-end WIRE mission simulation test.
- Deploy solar arrays at predicted cold extremes. **Note: the SMEX project usually performed two solar arrays deployments (hot and cold). However due to time constraints and test set-up only a cold deployment was performed at the spacecraft level.**

WIRE Test Objectives (Thermal)

- Validate the thermal design of the WIRE spacecraft at hot, cold, and safehold environmental extremes.
- Verify flight heater operation and thermostat set points for both the survival and operational heater buses.
- Obtain thermal balance points to validate the spacecraft thermal models.
- Determine qualitatively the effect of the environment on the dewar simulator.
- Confirm the interface conductance from electronics to composite panels is acceptable.
- Verify the Star Tracker thermal design.

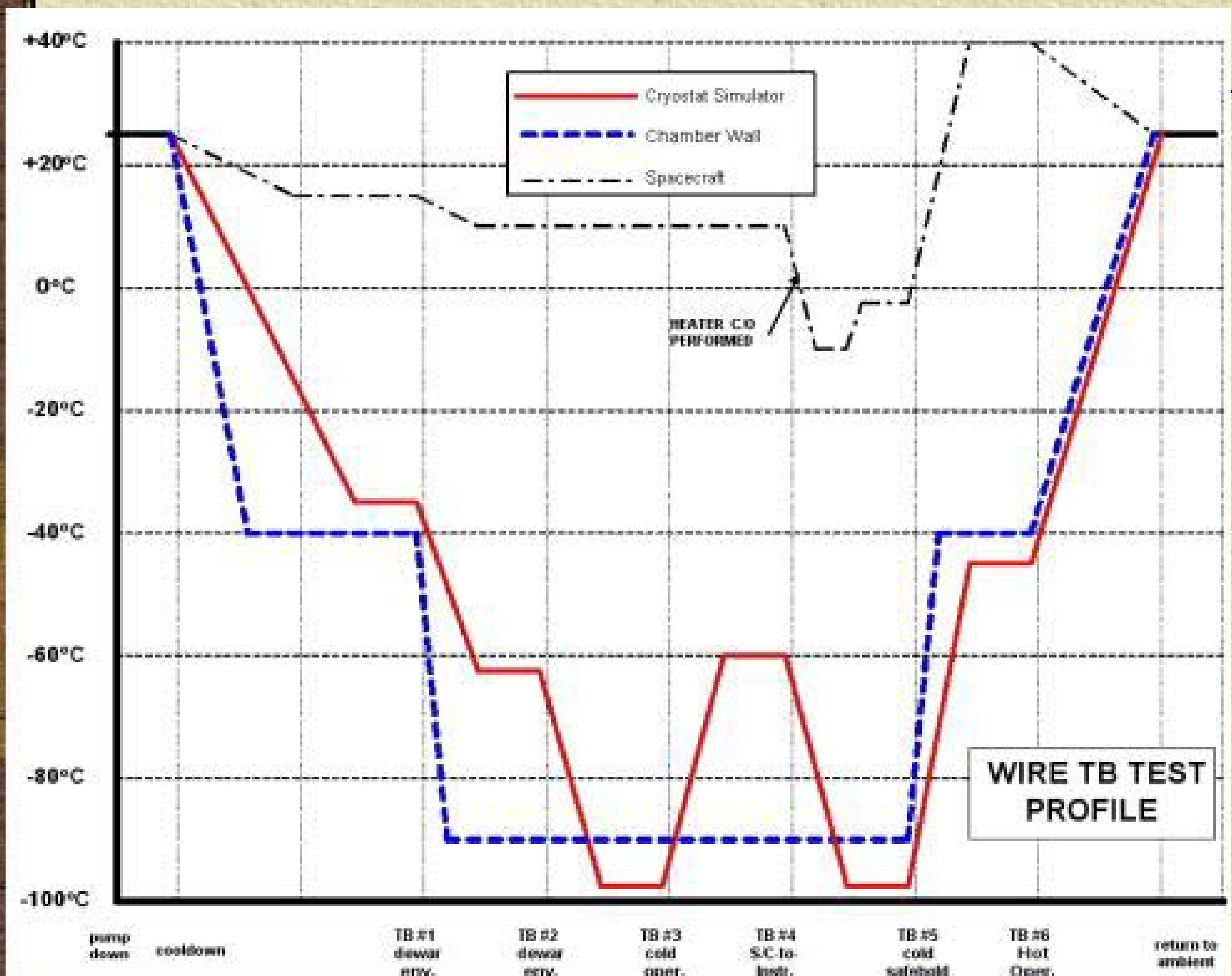
WIRE Test S/C Configuration

- **Thermal Balance**
  - ETU Solar Arrays With Flight Hinges, Dampers, Mechanisms, and Omni Antennas
  - Pegasus Ring Simulator
  - Cryostat Simulator With Flight Instrument Electronics (WIE)
  - All Other Components Are Flight Hardware
- **Thermal Vacuum** - Same Configuration As Thermal Balance Except:
  - Omni Hat Couplers and Star Tracker Stimulus
  - Additional S/C Test Cabling
  - Open MLI "Flaps" to Accommodate Test Cabling and Internal TQCM
- **Cold Solar Array Deployment**
  - Flight Solar Arrays, Hinges, Dampers, Mechanisms, and Omni Antennas

WIRE Thermal Testing

- **Six Thermal Balance Points**
  - Dewar Simulator Point 1 (simulator uncontrolled with walls at -40° C)
  - Dewar Simulator Point 2 (simulator uncontrolled with walls at -90°C)
  - Cold Operational
  - Instrument/Spacecraft Interface Verification
  - Cold Safehold (heater check-out)
  - Hot Operational
- **Four Thermal Cycles (16 hour soak time requirement)**
  - Cold Turn-on
  - Hot Turn-on
  - One Safehold Cold Plateau, Three Operational Cold Plateaus
  - Three Operational Hot Plateaus, One Decontamination Hot Plateau
- **Cold Solar Array Deployment**

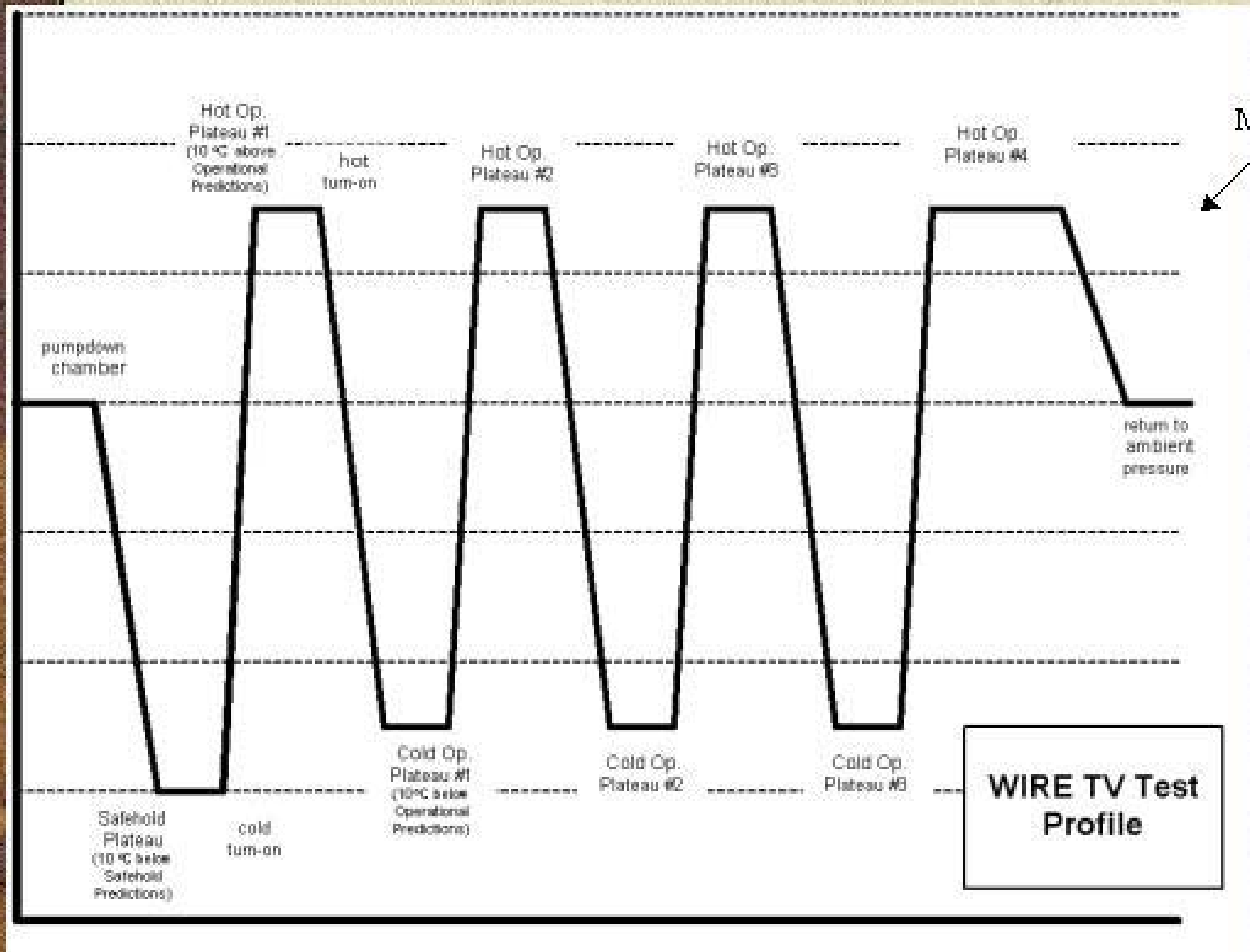
WIRE Thermal Balance Profile



Component power measurements at EACH balance point

Bus Voltage varied accordingly

WIRE Thermal Vacuum Test Profile

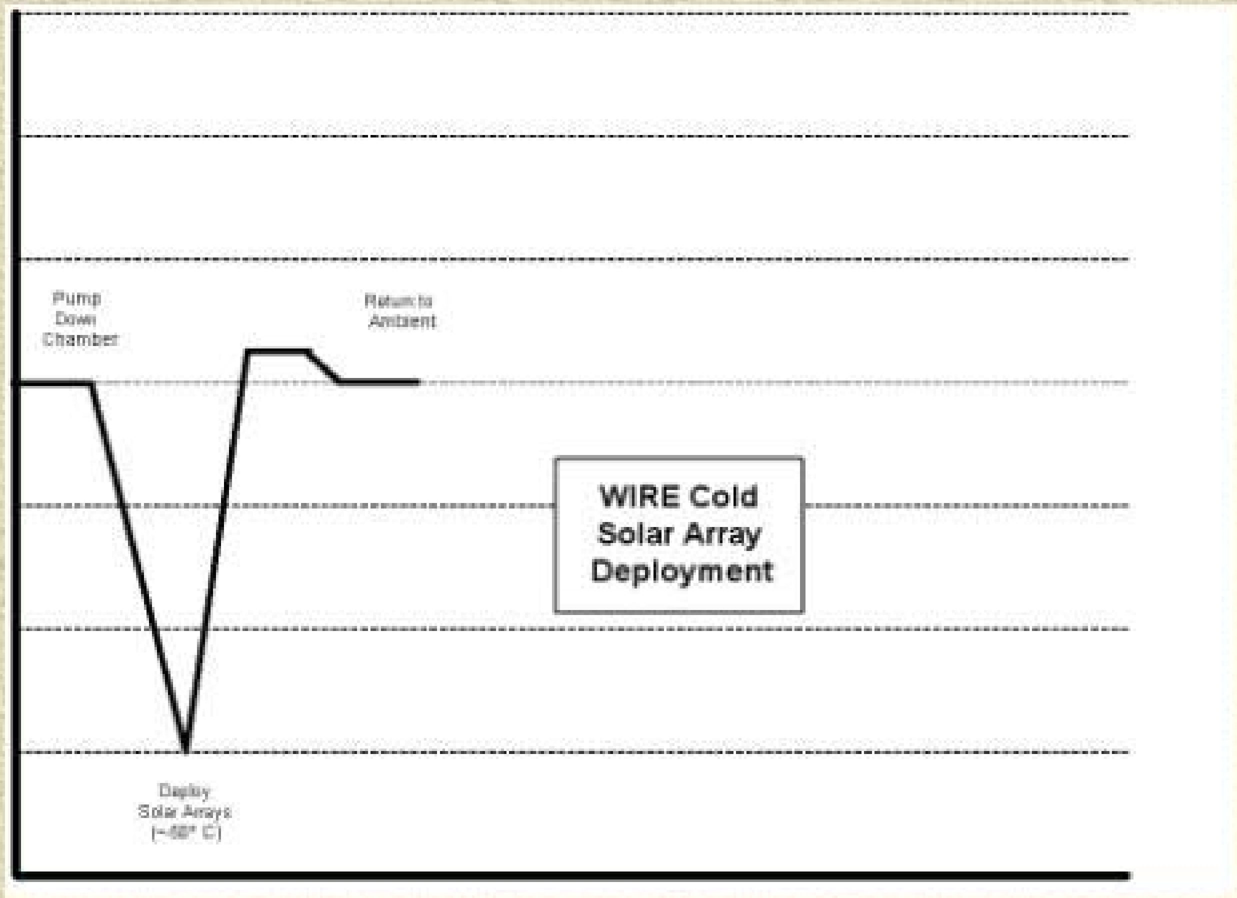


Component power measurements at EACH plateau

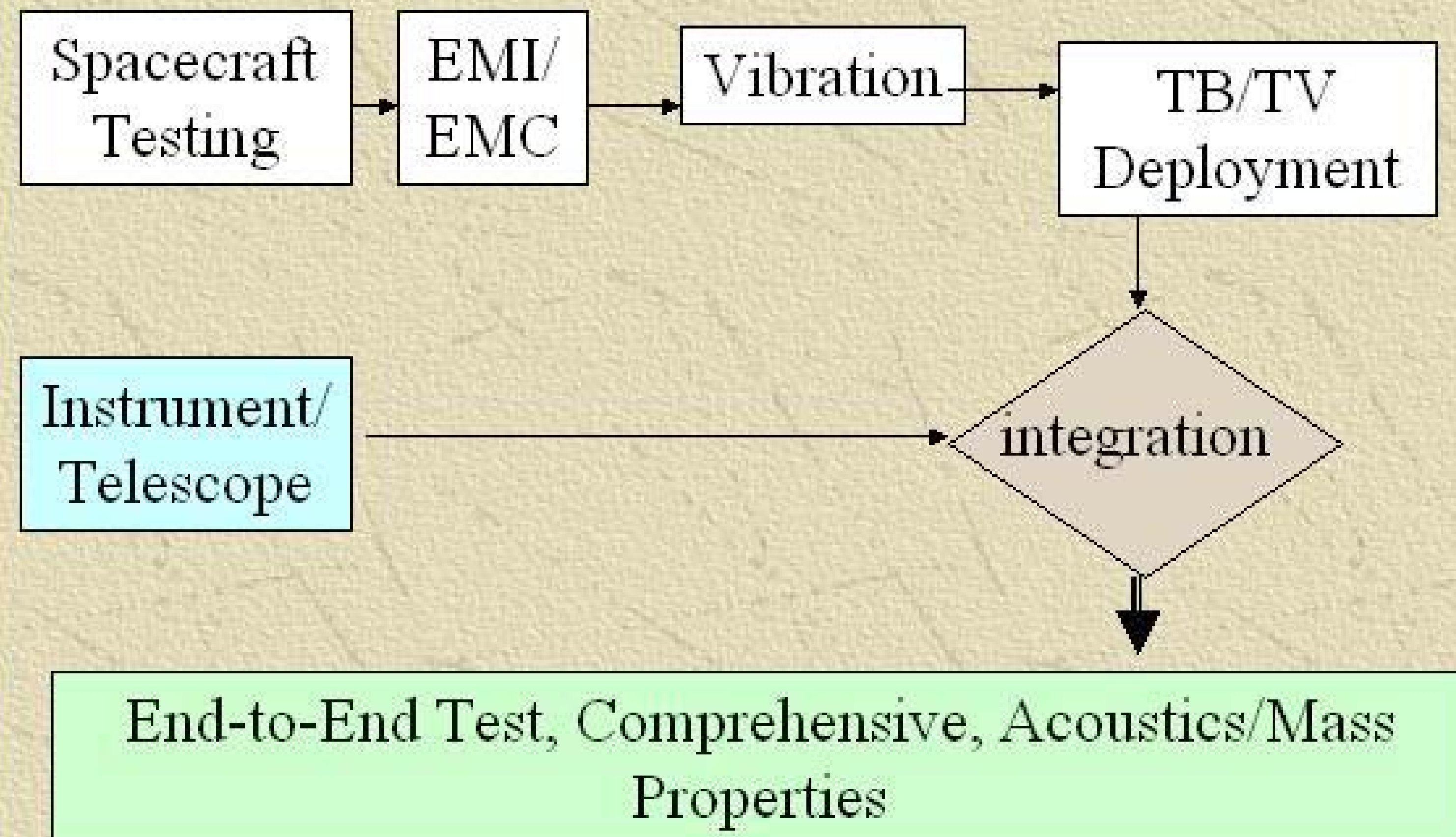
Levels based on correlated flight predicts

Bus Voltage varied accordingly

Cold Solar Array Deployment



Overall Test Program



Summary Step 2: Define Goals, Test Flow, and Interface Issues.

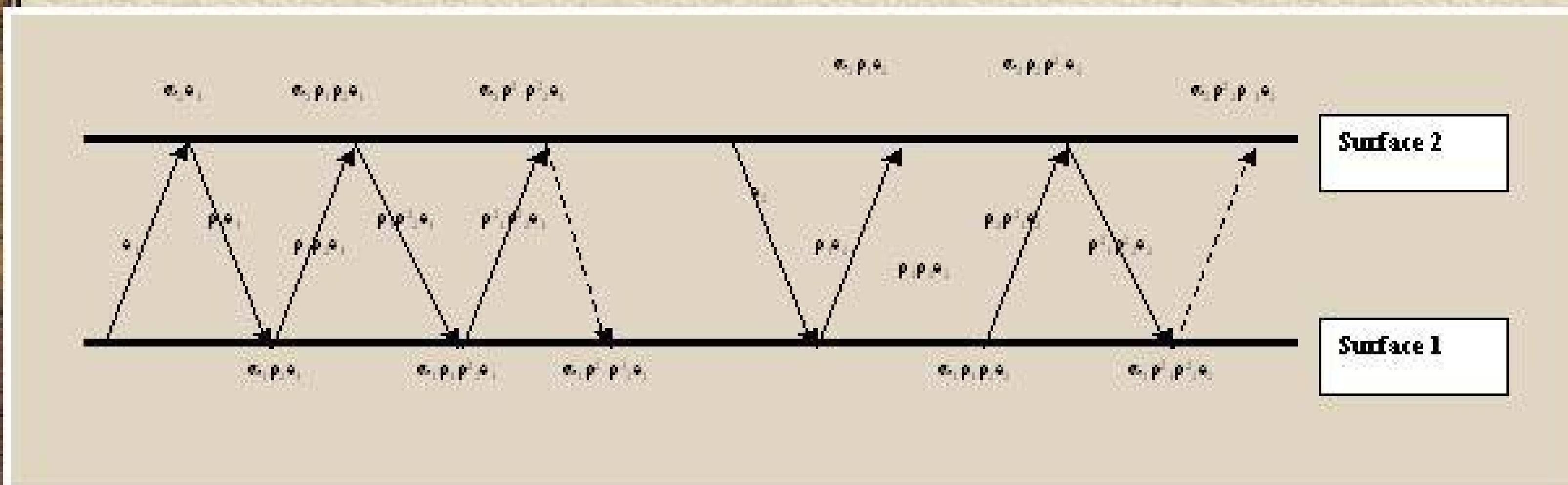
- Met with project, instrument personnel, and all system engineers to define goals.
- Identified major issue with having instrument in test. Devised a method of simulating the dewar and began designing/modifying hardware.
- Use of ETU Solar Arrays based lined for TB/TV. Flight Array qualification test planning begun.
- Selected balance cases and number of TV cycles.
- Determined S/C Configuration for the three tests.
- Created Test Timeline.

Step 3: Use Spreadsheet to Estimate Sink Temperatures

- **Thermal Balance**
  - Use the flight analysis results for worst cold, worst hot, and survival cases. Generate heat flow maps for all radiators, apertures, and interfaces. Information needed: radiator/aperture sizes, coatings properties used, absorbed fluxes, and predicted temperatures.
  - Perform spreadsheet calculations to determine approximately what the sink temperatures need to be. When determining this take into account "bounce back" effect for cryopanels. Make sure you match flight and test temperatures **AND heat flows**.
- **Thermal Vacuum**
  - Calculate sink temperatures needed to activate survival thermostats and to maintain temperatures at qualification limits to bound the requirements.

The Bounce Back Effect

- *No surface is a perfect absorber (like space).*
- *The amount of energy transferred to a cryopanel or the chamber is a function of the separation distance, temperatures, and surface properties.*



Energy Transferred to a Cryopanel Preliminary Calculations

$$Q_{rad\text{-}cp} = \sigma\, A_{rad}\, F_{rad\text{-}cp}\, (T^4_{rad} - T^4_{cp})$$

Where:

$$F_{rad\text{-}cp} = (1/\varepsilon_{cp} + 1/\varepsilon_{rad} - 1)^{-1}$$

cp-cryopanel
rad-radiator

"Bounce Back" may also be factor in calculating views to chamber depending on the distance between the walls and test article.

See "Methods" Presentation for plots on energy transfer to cryopanels/heater plates

Spreadsheet Sink Calculations

$$Q_{\text{rad-cp}} = Q_{\text{backload}} + Q_{\text{solar}} + Q_{\text{albedo}} + Q_{\text{IR}}$$

(or chamber)

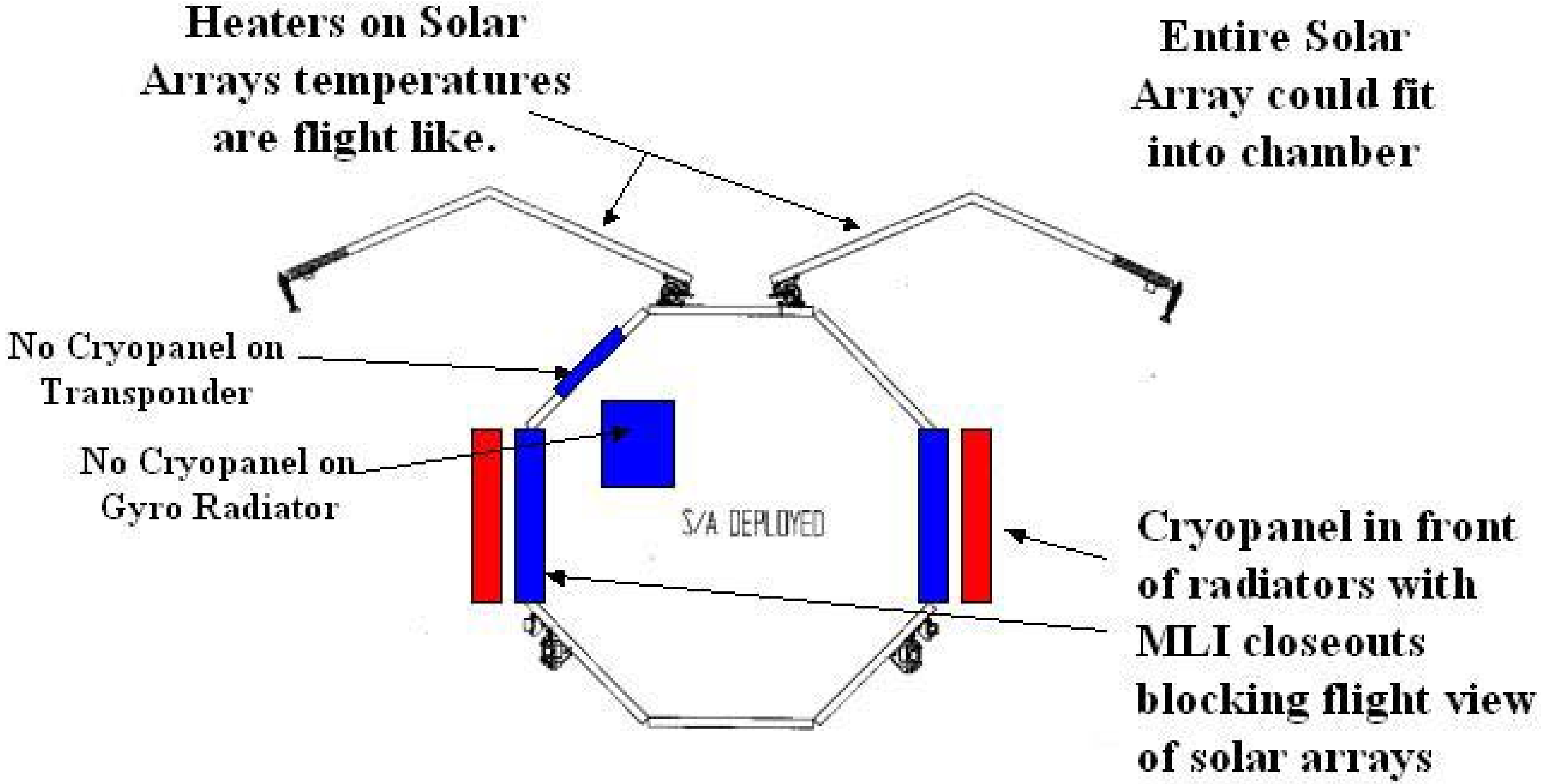
- Verify "order of magnitude" of environmental fluxes obtained in flight thermal model with cube calculations.
- Sum up absorbed fluxes if multiple nodes were used in the Thermal Model and area average radiator temperatures.
- Backloading calculations may need to be included.
- Calculate temperature for cryopanel or chamber wall for all phases of the test.

Backloading Effects

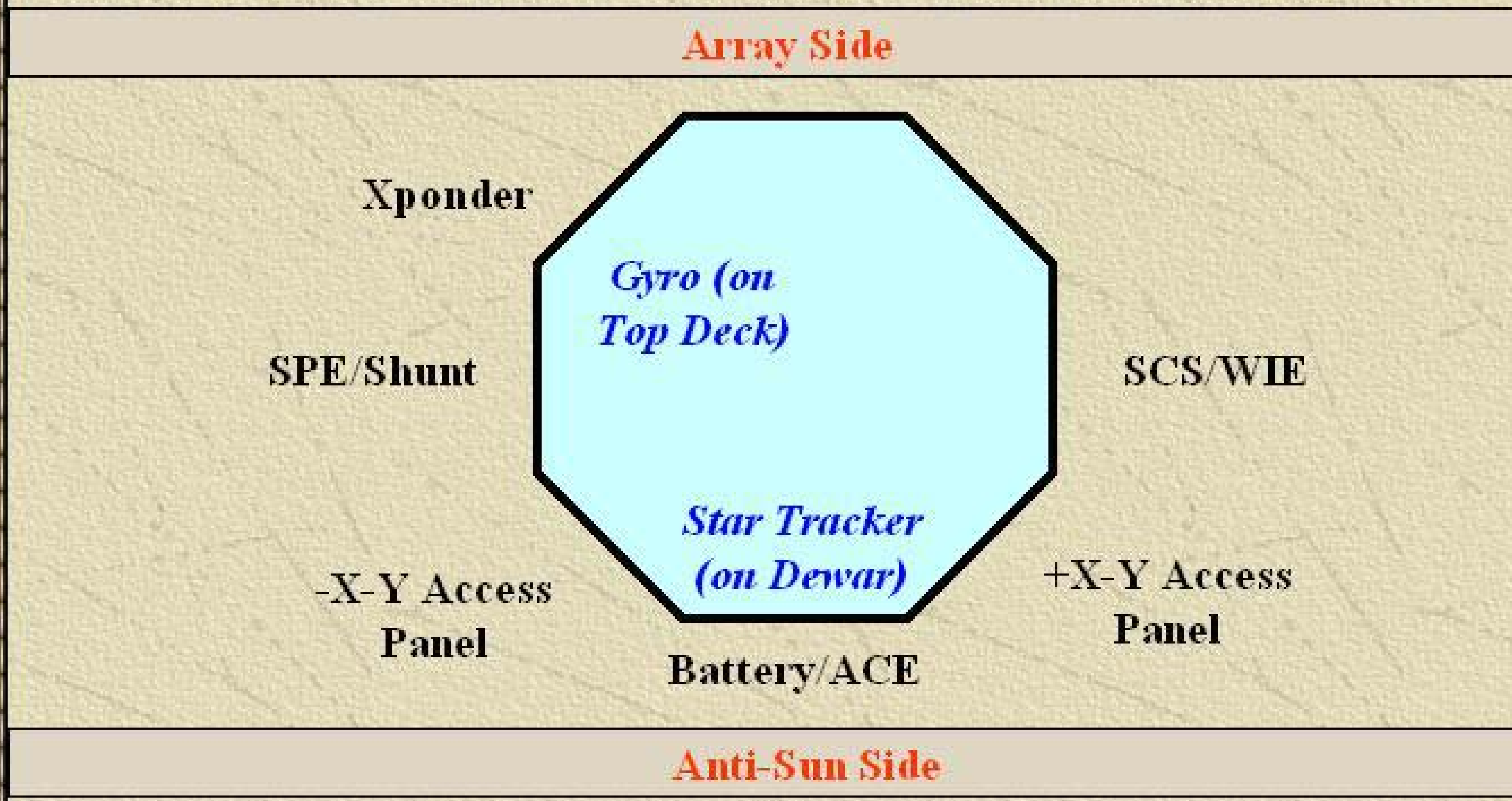
Backloading should be compensated for during thermal balance testing when:

- A component is not present.
- A component can not be controlled to flight temperatures.
- A cryopanel or other test GSE is blocking the view of radiators.

WIRE Backloading



Location of Components



Results of Spreadsheet Calculations Safehold, Cold, and Hot Balances

	ESTIMATED CHAMBER TEMP. SETTING (IN KELVIN) NO CRYOPANELS IN FRONT		
WIE	175.97	175.97	188.18
ACE	149.95	149.95	216.25
SPE	177.29	177.29	187.95
XPONDER	202.75	202.75	247.48
SCS	178.35	178.35	195.37
BATTERY	162.22	162.22	221.93
SHUNT	177.89	177.89	195.57
GYRO	119.51	119.51	107.11

	ESTIMATED CHAMBER TEMP. SETTING (IN KELVIN)		
using net minus array input			
WIE	182.78	180.68	193.80
ACE	67.67	68.49	184.63
SPE	183.89	182.96	193.99
XPONDER	257.31	262.21	306.37
SCS	179.59	177.25	192.33
BATTERY	70.22	70.22	198.28
SHUNT	188.51	187.17	195.08
GYRO	231.02	231.75	256.67

Temperatures in Kelvin

	ESTIMATED CHAMBER TEMP. SETTING (IN KELVIN)		
51100	251.09	251.20	270.90
51200	202.69	202.73	248.18
51400	156.07	156.10	206.89
51600	159.18	159.18	207.08
52100	251.12	251.10	275.08
52200	184.29	184.28	196.50
52400	167.75	167.72	211.96
52600	166.99	166.97	212.00
52800	181.78	181.86	195.70
AVERAGE	191.22	191.24	224.92

For MLI

Summary Step 3: Calculate Sink Temperatures

- Summarized Radiator Areas, Absorbed Fluxes, View Factors from Flight Model.
- Calculated Average MLI Sink Temperatures.
- Calculated Radiator Sink Temperatures with and without Cryopanels (Accounting for “bounce back”).

Step 4: Use the Information Obtain to Define a Preliminary Test Set-up

- Looking at the average MLI sink temperatures chamber temperatures were within GN_2 control range.
- The major input to the Transponder was the back loading from the solar arrays. The chamber temperatures listed above produced only a small difference in between flight and test energy balances. Therefore it was decided to not have a Cryopanel in front of this radiator.
- There was no physical room for a cryopanel for the Gyro.
- Radiators on the $\pm$X faces (SCS/WIE and SPE/Shunt) were within GN_2 control range. Sink temperatures were similar enough for each "pair" to have a single Cryopanel. These cryopanels were removed prior to S/A deployment test.

Step 4 Continued

- Anti-Sun radiators needed LN_2 sink for cold cases and GN_2 sink for hot cases. LN_2 Cryopanels with heaters/flow control were selected. The battery Cryopanel required separate control to achieve desired temperatures in thermal vacuum. The ACE and access panels were controlled together.
- Two cryopanels were used for the Star tracker. One for the radiator and one for the aperture. In TV a stimulus was put on the tracker and the aperture cryopanel was removed.
- There were only THREE Thermal Conditioning Units (TCU) available for this test.

Cryopanels and Cold Plates

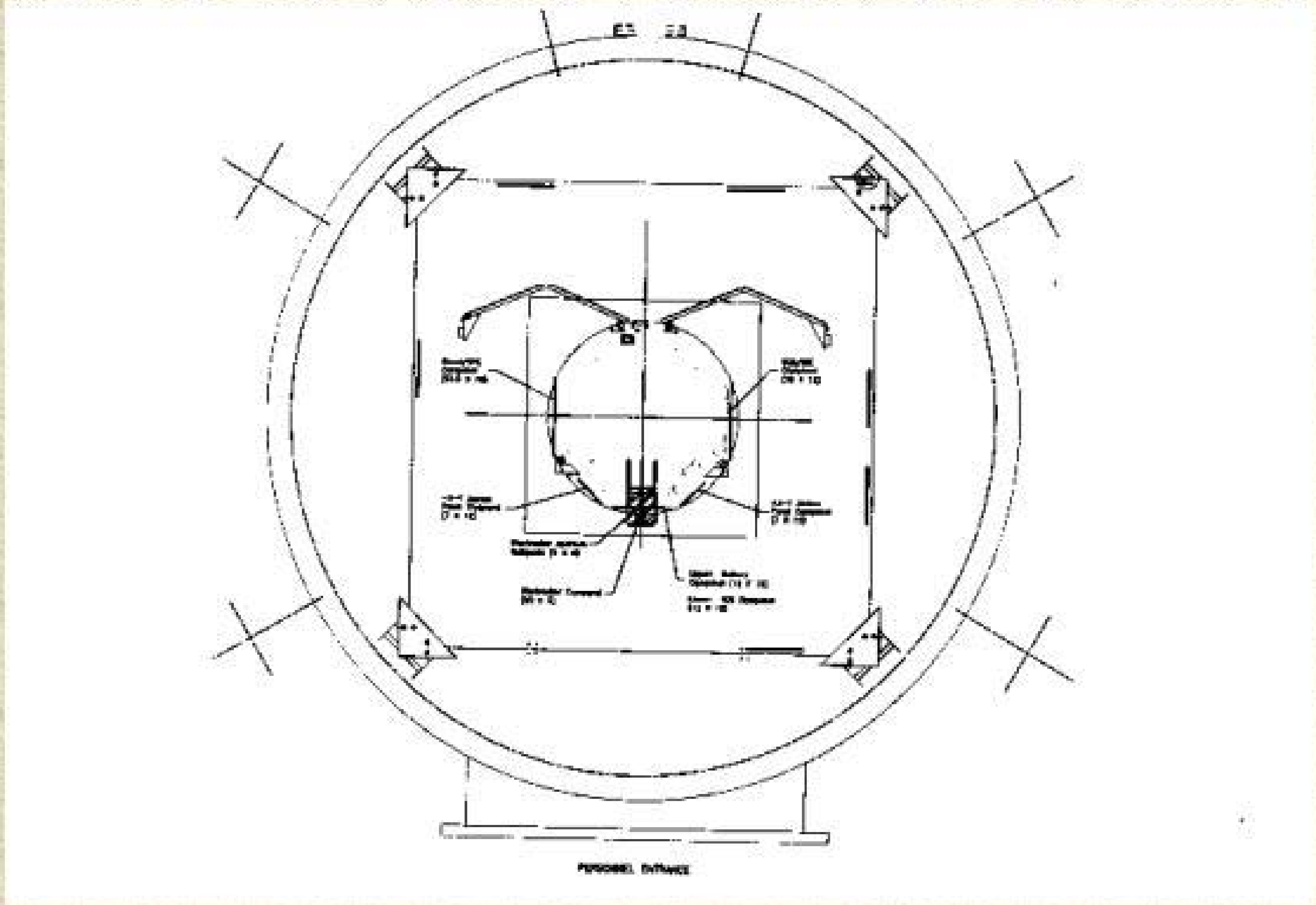
Item	Size	Control
Battery cryopanel	12" x 12"	LN2 with heaters
ACE cryopanel	12" x 12"	LN2 with heaters
-X-Y access panel cryopanel	7" x 12"	LN2 with heaters
+X-Y access panel cryopanel	7" x 12"	LN2 with heaters
Startracker shade cryopanel	5" x 22"	LN2 with heaters
Startracker aperture cryopanel	6" x 6"	LN2 with heaters
SCS/WIE Cryopanel	29" x 16"	GN2
SPE/Shunt Cryopanel	24.5" x 16"	GN2
Dewar Simulation Cold Plate	18" diameter, 24" height	GN2

Cryopanels chosen from existing hardware at Goddard

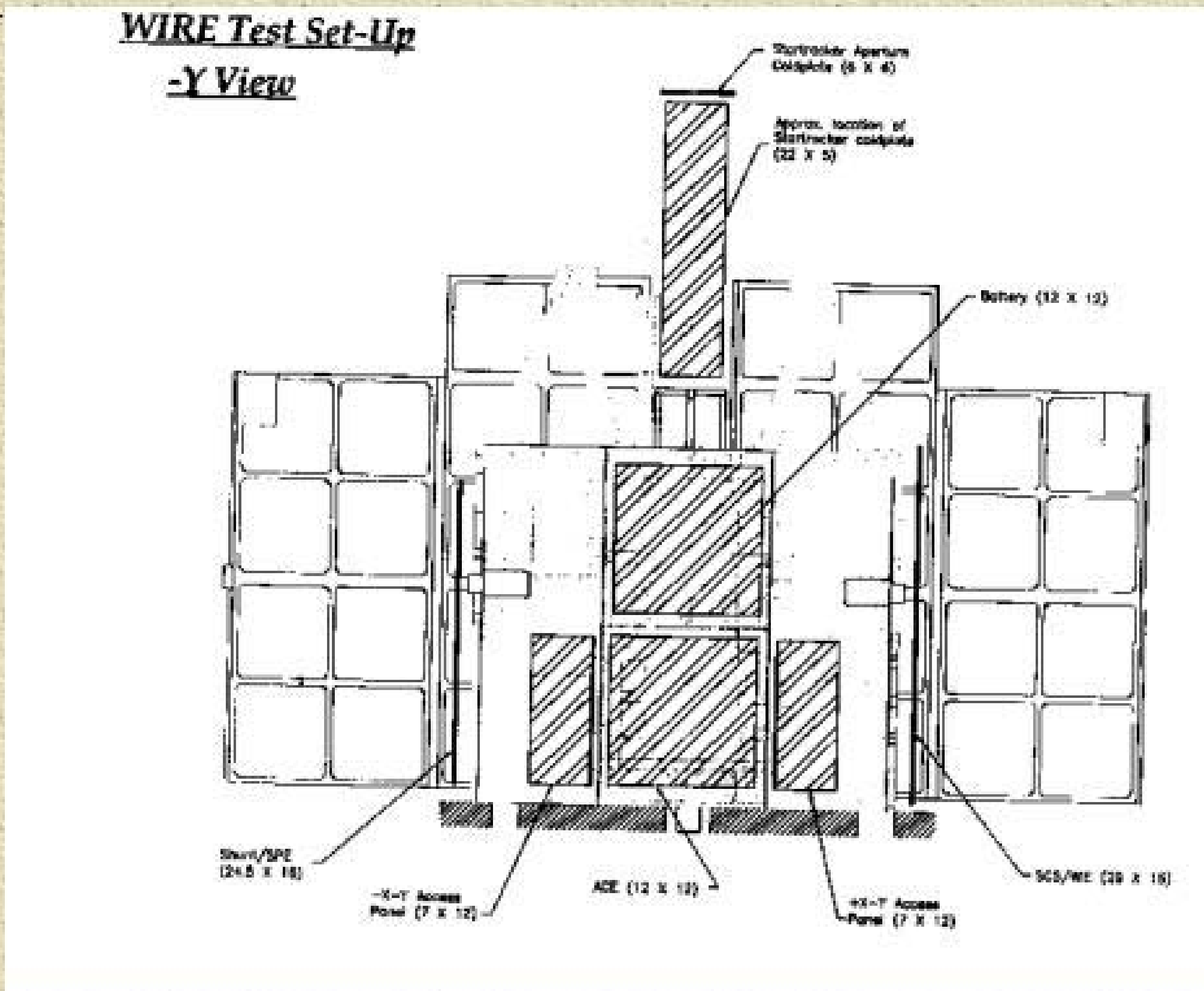
WIRE Test Set-up

- Cryopanels for all radiators except the gyro and transponder. These two components will utilize the chamber wall as their sink.
- Test heaters on components to:
  - Help achieve TV goals
  - Provide protection
  - Maintain temperatures when instrument or S/C components are off
  - Speed transition to hot plateaus
  - Simulate environmental fluxes (S/A, Mag. boom, Dewar,+Y MLI, Pegasus simulator)
  - Provide zero-Q on cables and mounting fixture
- Actively controlled Dewar simulator
- thermocouples

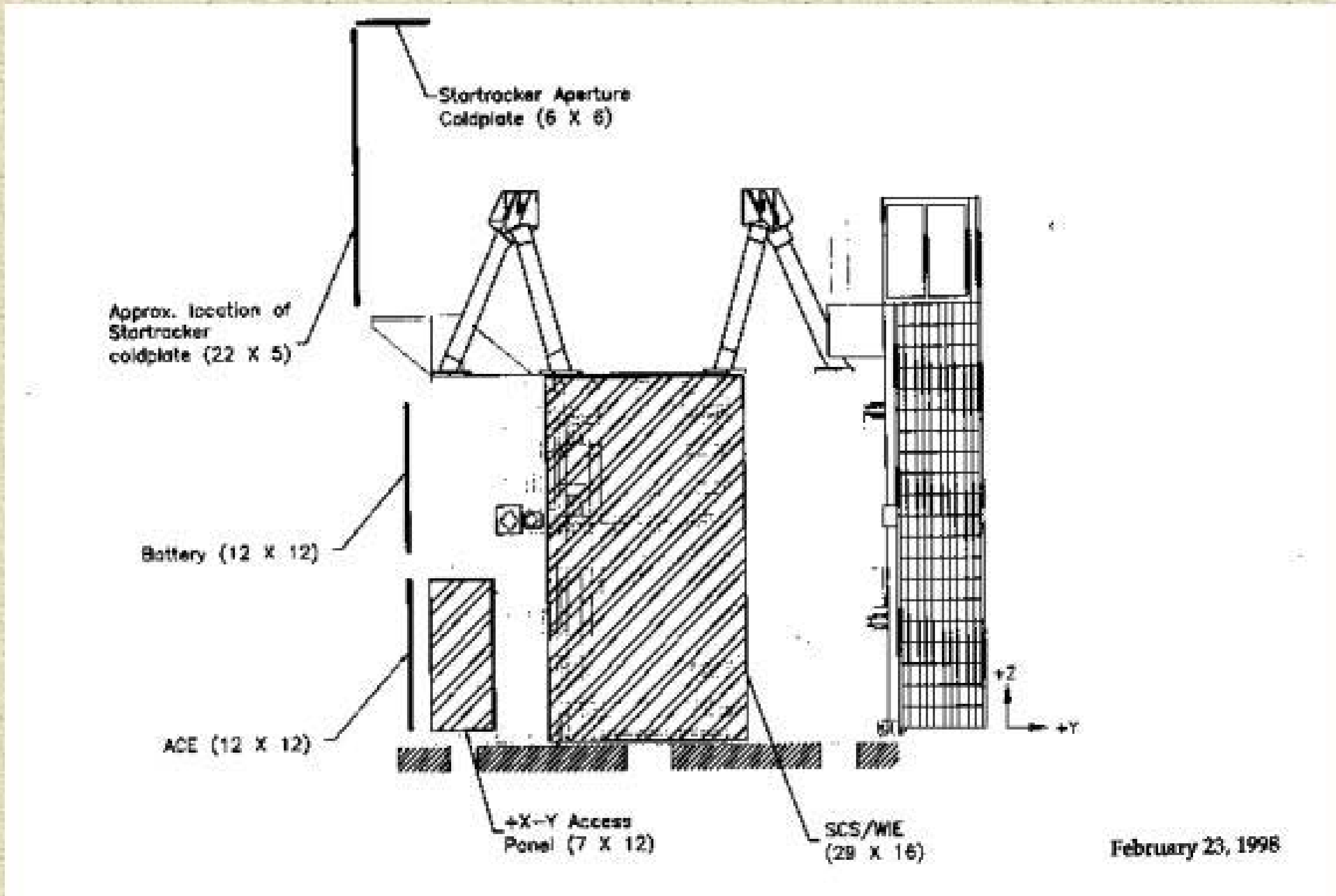
WIRE Test Set-up (Top View)



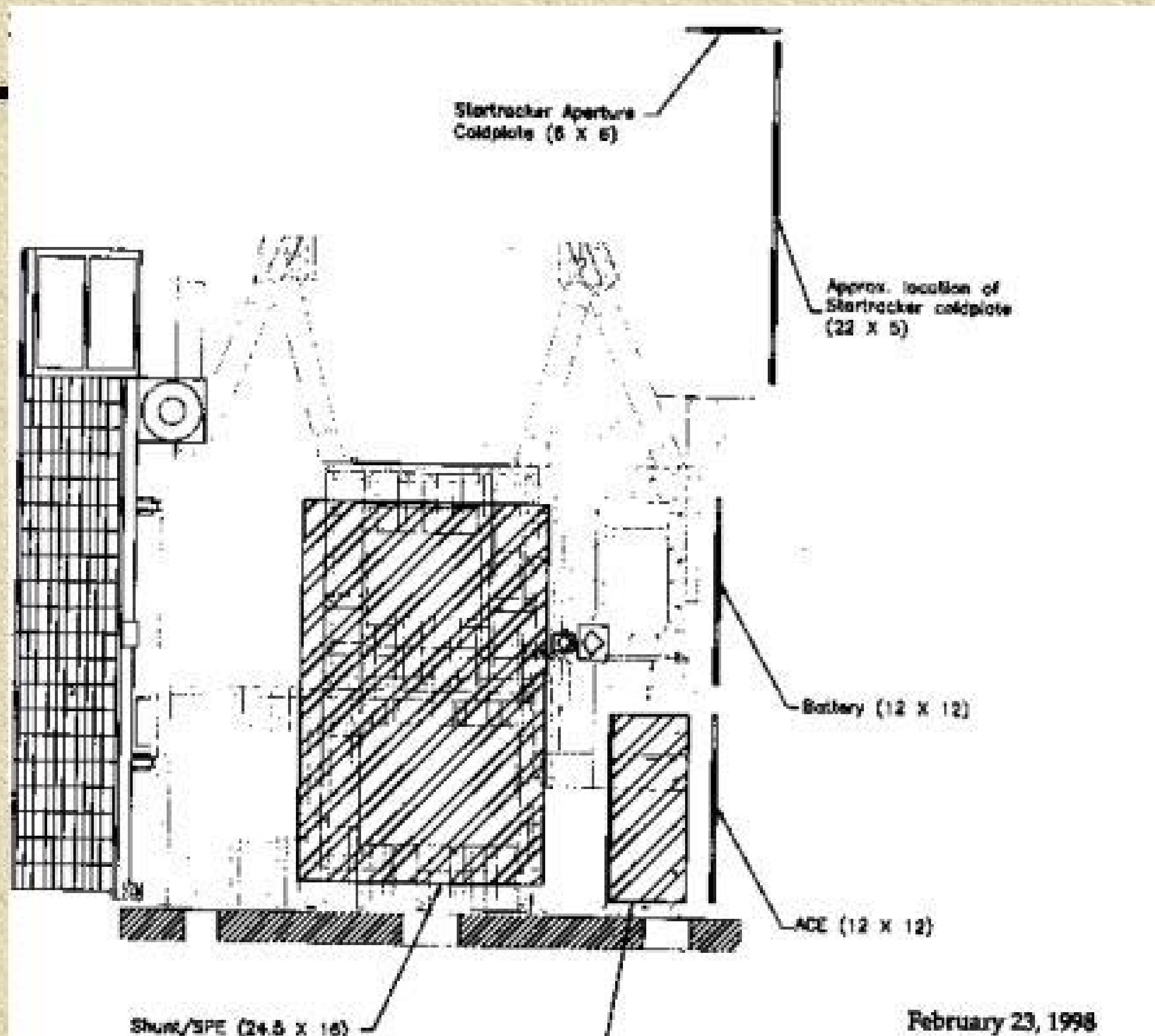
WIRE Test Set-up - Y View



WIRE Test Set-Up +X-Y View



WIRE Test Set-up -X-Y View



Picture of WIRE

S/A Deployment Test

- Access panel radiators were moved to allow these cryopanels to remain during S/A deployment test.
- $\underline{+}$X Cryopanel removed prior to test.
- Omni hat couplers removed prior to test
- ***Flight Arrays had to be installed.***
  - Since heaters could not be mounted to the flight arrays an alternate method of temperature control had to be devised.
  - Large heater panels were designed to warm the panels to +30°C.
  - Concerns about non-flight gradients in the composite arrays led to a detailed analysis to determine the proper size and heater circuit lay-out. Since this piece of GSE was not used in TV/TB there was an extra month of fabrication schedule.

Summary Step 4: Use Information to Define a Preliminary Test Set-up

- Determined control ranges for all radiators
- Selected existing cryopanels
- Began studies of solar array heater panel
- Started design of Cryopanel support structures

In less than three weeks there was a clear plan and action items to complete long lead time hardware and to define unknowns. Of course the work was just starting!

The Next Steps

- Size test heaters on components using spreadsheet
- Define test sensor locations and test MLI
- ***Work with project to ensure accurate power measurements of all components during test***
- Update flight models with configuration changes
- Create detailed model of test set-up
- Perform test and flight analysis with updated models.
- Complete component level test summary and set preliminary TV levels
- Define contamination requirements & hardware
- Write test plan/procedure

Hardware

- One of the most important job of the thermal engineer is to ensure that the flight and test hardware is build and installed properly. Physically measure radiator areas and MLI dimensions. Verify that the analytical model and the hardware agree.

Analytical Models

- Build ONE model for test and flight with "Cases" defined in Variables 1. This way if you update a parameter (like a conductance coupling) ALL analyses will have the update. Using this method, less errors are introduced and model correlation is much faster.

Other Areas of Concern that Led to Additional Analysis/Testing

- Validation of Star Tracker Thermal Design.
- Magnetometer was not cycled to the required temperature levels and had to be requalified at the component level. (Survival Limit -40°C, Tested to -20°C, Cold Flight Predict -22°C).
- Paint fell off the coatings "coupon" associated with the dewar simulator when subjected to vacuum. Dewar simulator had to be cycled in vacuum prior to installation on the observatory.
- Effect of solar input on the Pegasus ring was questioned. Another balance point, a Pegasus ring parametric study, was added.

The Test

- Thermal Model and Test Data in Good Agreement.
- Flight Environment and Test Levels Independently Verified.
- TV Levels Based on Model Predicts with Test "Offset".
- Heaters
  - WIE Operational Heater Failure.*
  - Gyro Operational and Survival Thermostat Switched.*
  - SCS Heaters Not Utilized.
- One Thermal Controller on LN_2 Cryopanel/Heater system Failed During TV Test.
- Deployment Test Successful.

**** No Corrective Action Required***

WIRE Test Data Heater Verification

Component	Measured Current (Amps)	Power (Watts)	Specified Turn-On (Celsius)	Specified Turn-Off (Celsius)	Measured Turn-On Turn-on	Measured Turn-off (Celsius)
Battery Operational	0.456	10	2.0	8.0	1.7	11.3
Battery Survival	0.240	5	2.0	8.0	1.8	7.3
Gyro Operational	0.325	7	6.0	13.0	2.4	8.4
Gyro Survival	0.500	10	2.0	8.0	7.7	14.3
ACE Operational	0.319	7	-8.0	-2.0	-7.1	-0.1
ACE Survival	0.350	7	-8.0	-2.0	-7.0	U
WIE Survival Operational Failed	0.255	5	-11.7	-6.5	-12.6	-7.3

U – Heater turned off. However, the exact temperature of turn-off was indeterminate

WIRE Heater Verification - Continued

Component	Measured Current (Amps)	Power (Watts)	Specified Turn-On (Celsius)	Specified Turn-On (Celsius)	Measured Turn-On Turn-on	Measured Turn-off (Celsius)
SPE Operational	0.351	7	-8.0	-2.0	-4.6	U
SPE Survival	0.348	7	-8.0	-2.0	-5.0	1.7
SCS Op & Surv	None	5 & 5	-8.0	-2.0	The SCS Never Got Cold Enough for Turn-on	
ST Operational	0.770	17	-18.0	-12.0	-16.3	-10.7
ST Survival	0.826	17	-18.0	-12.0	-16.8	-11.7
S/A Damper –X	0.220	3	2.0	8.0	-1.2	1.2
S/A Damper +X	0.220	3	2.0	8.0	0.5	3.8

U – Heater turned off. However, the exact temperature of turn-off was indeterminate

TB Data Versus Test Predictions

	SURVIVAL CASE			COLD CASE			HOT CASE		
DESCRIPTION	PREDICT	DATA	DELTA	PREDICT	DATA	DELTA	PREDICT	DATA	DELTA
SCS Baseplate	-3	1	4	10	8	-3	33	30	-4
WME Baseplate	-13	-12	0	12	13	1	38	42	4
ACE Baseplate	-4	-3	1	15	14	0	43	44	1
BATTERY Baseplate	5	5	0	5	6	1	16	18	2
SPE Baseplate	-5	-3	2	1	3	3	30	30	-1
SHUNT Baseplate	1	2	1	3	6	3	31	27	-3
XPONDER Baseplate	1	3	2	9	10	1	44	48	4
GYRO	5	5	0	16	15	-1	37	34	-3
WHEEL Y	5	5	0	14	10	-5	41	38	-3
WHEELS AC	-1	1	2	14	10	-4	42	37	-4
DSS head	-9	-7	1	-1	-2	-1	30	30	-1
DSSE	2	2	-1	15	10	-5	45	43	-3
EARTH SENSOR +X	8	12	4	19	18	-2	44	36	-8
EARTH SENSOR -X	13	14	1	15	15	1	39	32	-7
WAES	6	8	2	16	16	0	46	47	1
PYRO	-5	-5	0	9	9	0	40	43	3
MAG HEAD	-10	-15	-4	-10	-14	-4	3	-1	-4
Omni Antenna	-16	-16	0	-16	-16	-1	12	14	2
X TORQUER ROD	-1	1	2	7	8	1	41	44	3
Y TORQUER ROD	-3	-5	-2	6	5	0	40	42	2
Z TORQUER ROD	10	1	-8	9	6	-3	39	40	1
ST HOUSING	-20	-16	4	5	2	-2	18	19	0
ST LIGHTSHADE AVE	-35	-36	0	-11	-14	-3	-3	-5	-2
LOWER DECK-average	-13	-11	2	-2	1	3	48	45	-3
UPPER DECK-average	-3	-2	1	6	3	-3	32	26	-6
RESISTOR PANEL	-4	-1	3	6	3	-3	34	32	-2
DBWAR mainshell *	-105	-100	5	-103	-99	4	-43	-42	0

* with no corrections to model to account for blanket area differences

TB Heater Power Versus Predicts

Description	Cold Operational			Cold Survival		
	% Duty Cycle	Test Power	Predict Power	% Duty Cycle	Test Power	Predict Power
SPE Operational Survival	Off Off	0 0	0 0	Off 31%	0 2.2 W	0 2.2 W
SCS Operational Survival	Off Off	0 0	0 0	Off Off	0 0	0 0
ST Operational Survival	Off Off	0 0	0 0	21 % Off	3.6 W 0	5.2 W 0
Battery Operational Survival	67% Off	6.7 W 0	7.2 W	48% 100%	4.8 W 5.0 W	5.1 W 5.3 W
Gyro Operational Survival	Off Off	0 0	0 0	Off 100%	0 10.0 W	0 10.7 W
ACE Operational Survival	Off Off	0 0	0 0	Off Off	0 0	0 0
WIE Survival Operational Failed	Off	0	0	100%	5.0 W	5.0 W
TOTAL		**6.7 W**	**7.2 W**		**30.6 W**	**33.5 W**

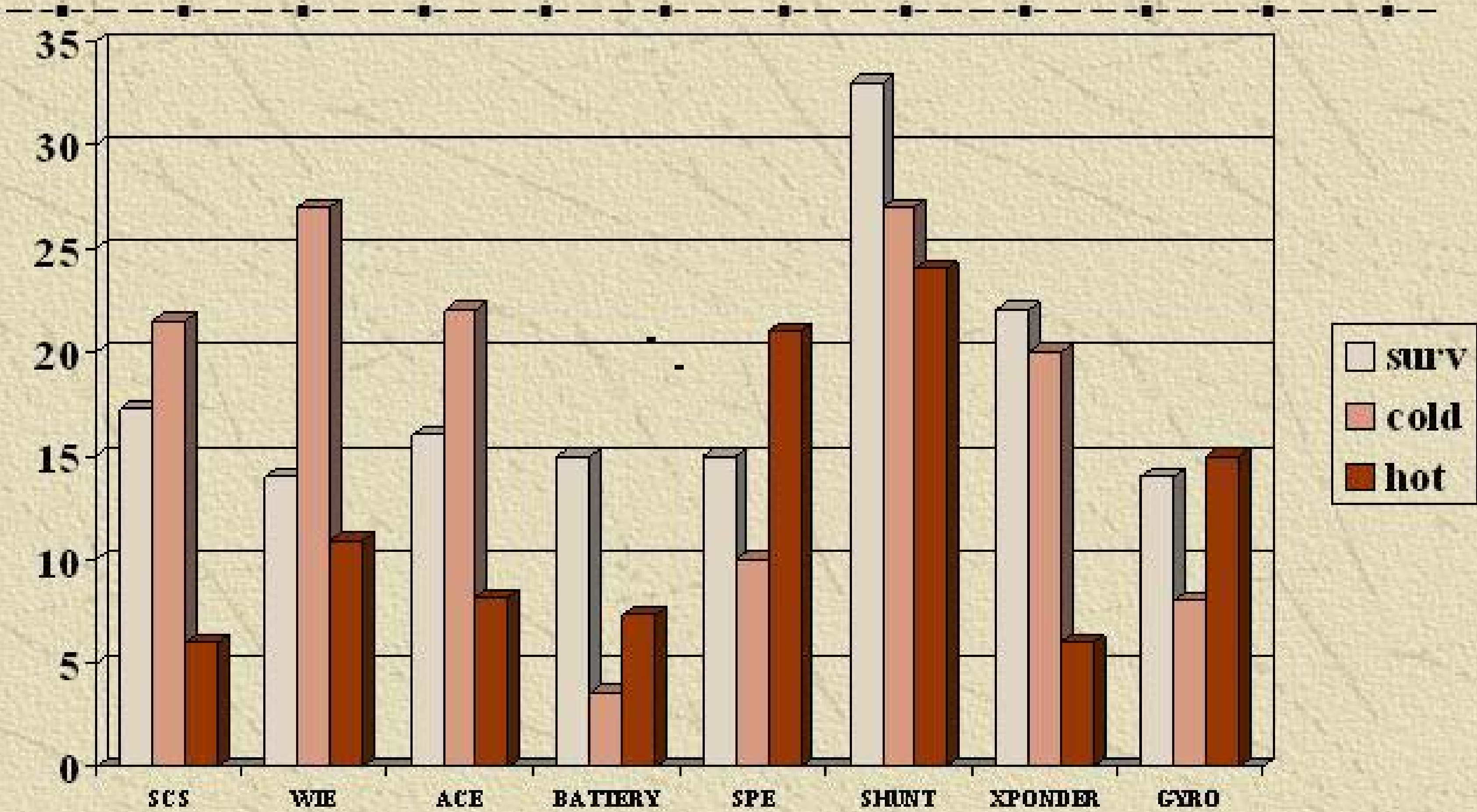
Post-Test Flight Power Dissipations

Component decription	POWER DISSIPATION		
	SURV	COLD	HOT
SCS	19.5	19.5	19.5
WIE	OFF	25.2	27.4
ACE	22.2	33.6	38.0
BATTERY	3.0	2.9	3.3
SPE	7.0	8.0	8.0
SHUNT	6.0	3.0	10.0
XPONDER	4.7	4.7	8.9
GYRO	OFF	10.0	6.0
Reaction wheel y	3.0	3.0	3.0
Reaction Wheels A-C	OFF	3.0 each	3.0 each
DSS Head	0.1	0.1	0.1
DSSE	0.4	0.4	0.6
Earth Sensor +X	0.8	0.8	0.8
Earth Sensor -X	0.8	0.8	0.8
WAES	0.8	0.7	0.7
pyro	OFF	OFF	OFF
Magnetometer head	0.05	0.05	0.1
X Torquer rod	0.1	0.1	0
Y Torquer rod	0.3	0.1	0
Z Torquer Rod	0	0.1	0
Star tracker	OFF	6.9	8.0

Power in Watts

Thermal Design Margins

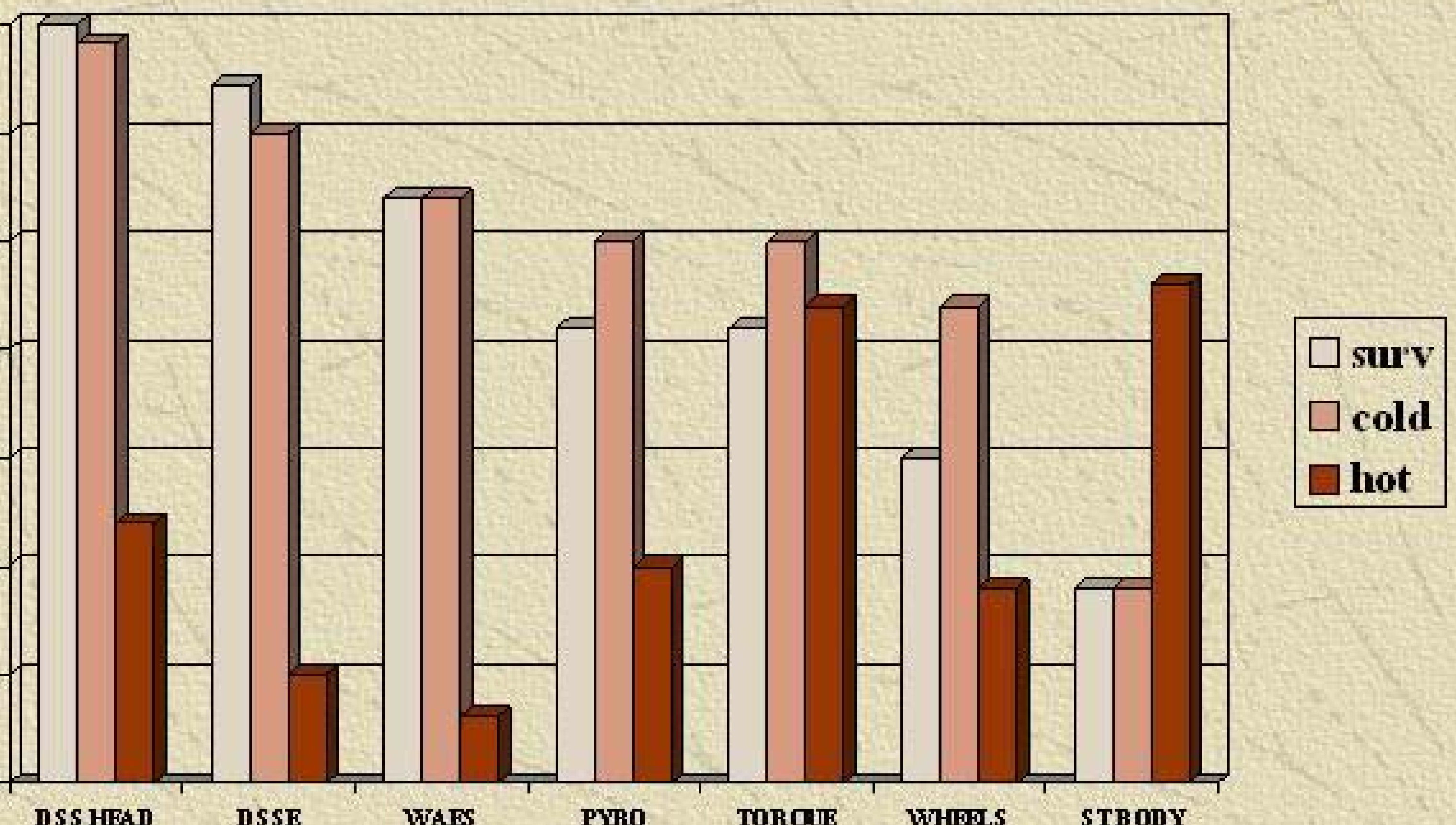
(Post Model Correlation, In Degrees Celsius)



Margin is defined as limit minus adjusted predict. Flight predicts were adjusted by test correlation deltas whenever it was conservative.

Thermal Design Margin - Continued

(Post Model Correlation, In Degrees Celsius)



Margin is defined as limit minus adjusted predict. Flight predicts were adjusted by test correlation deltas whenever it was conservative.

The SPE Thermal Qualification History

- Limits –10/+50°C operational, -20/+60°C survival.
- Operational and Survival Heater with Thermostat Set Points at –8/-2°C.
- Tested to –20/+60°C 8 cycles with 4 hour dwells.
- Thermal Balance Test
  - Cold Balance 3.2° C 0% Heater Duty Cycle
  - Survival Balance –2.4° C 31% Heater Duty Cycle
  - Hot Balance 29.8° C 0% Heater Duty Cycle
- Model Predicts within 3° C of Data.
- Four Cycles with >16 hr soak times, –10/40° C
  - TV Cold –9.2° C, -10.9° C, -10.6° C, -11.8° C
  - TV Hot 41.9° C, 45.3° C, 40.3° C, 43.7° C

Summary of Results

- Component Level TV Performed per GEVS.
- S/C & Instrument Electronics TV/TB Test Conducted per GEVS.
- Temperature & Heater Power Margins Acceptable.