WISE CRYOGENIC SUPPORT SYSTEM DESIGN OVERVIEW AND BUILD STATUS

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ABSTRACT

The Wide-Field Infrared Survey Explorer (WISE) is a NASA MIDEX mission that is being developed by the Jet Propulsion Laboratory (JPL) to address several of NASA's Astronomical Search of Origins (ASO) objectives. The WISE instrument, developed by the Space Dynamics Laboratory (SDL), is a 40-cm cryogenically-cooled telescope operating at < 17K, with four infrared focal planes, two of which operate at 7.8 K and two of which operate at 32 K. Cooling of the instrument is accomplished by a dual-stage solid hydrogen cryostat that is developed by the Lockheed Martin Advanced Technology Center (LMATC). The drivers for the cryogenic support system design are the 7-month lifetime, temperature requirements, and limiting heat loads into the open aperture.

This paper provides an overview of the WISE cryogenic support system design and a status of the flight system build.

KEYWORDS: Cryogenic cooling, solid hydrogen, cryostat, thermal, WISE

WISE MISSION OVERVIEW

The Wide-field Infrared Survey Explorer (WISE) mission is a NASA medium explorer project (MIDEX) being developed under the direction of the Jet Propulsion Laboratory (JPL), with a primary goal to provide an all-sky survey in four infrared imaging channels covering from 2.8 to 25 μm with over 500,000 times the sensitivity of previous all-sky surveys. In particular, WISE will: find the most luminous galaxies in the Universe, find the closest stars to the Sun, detect Main Belt asteroids larger than 3-km, contribute to our understanding of star and galaxy formation, provide an essential catalog for the JWST, and provide a lasting research legacy.

WISE will be launched into a 530-km, sun-synchronous, polar orbit in November 2009. During the seven-month primary mission, WISE will perform eight surveys, which will be combined to provide a single, high sensitivity full-sky survey.

This paper will present a brief overview of the cryogenic support system (CSS) design followed by a description of the current status of the CSS fabrication and assembly at the Lockheed Martin Advanced Technology Center (LMATC) and the Space Dynamics Laboratory of Utah State University Research Foundation (SDL). More detailed descriptions of the WISE instrument and the CSS design have been published previously[1,2].

WISE INSTRUMENT OVERVIEW

The WISE instrument (Figure 1) consists of a cryogenically cooled optical subassembly (OSA) consisting of a 40-cm afocal telescope, a scan mirror, imaging optics, and a beam splitter assembly (BSA). The BSA partitions the collected energy from the afocal telescope into four bands—two 32 K HgCdTe FPMAs mid-wave infrared (MWIR) bands, and two 7.8 K Si:As FPMAs long-wave (LWIR) bands.

The entire OSA is housed inside the cryostat cavity. The sole purpose of the primary tank is to cool the two LWIR FPMAs operating at 7.8±0.5K, while the larger secondary tank cools the rest of the OSA to <13K. The OSA mounts to a single flange on the inside of the secondary tank for a straight-forward and reliable integration. This flange mechanically supports the OSA and thermally ties it to the secondary tank. The primary tank is connected to the LWIR FPMAs via a flexible, shrink-fit style, thermal link. The links consists of beryllium end fittings attached to copper braids.

A two-stage aperture shade minimizes the thermal backload into the telescope and protects the telescope from the external environment. The outer stage or shade attaches directly to the cryostat vacuum shell. The inner shade is isolated from the outer shade and is radiatively cooled to less than 110K. A pyrotechnically actuated aperture cover hermetically seals the vacuum shell during ground operations and is jettisoned on-orbit to expose the telescope aperture.

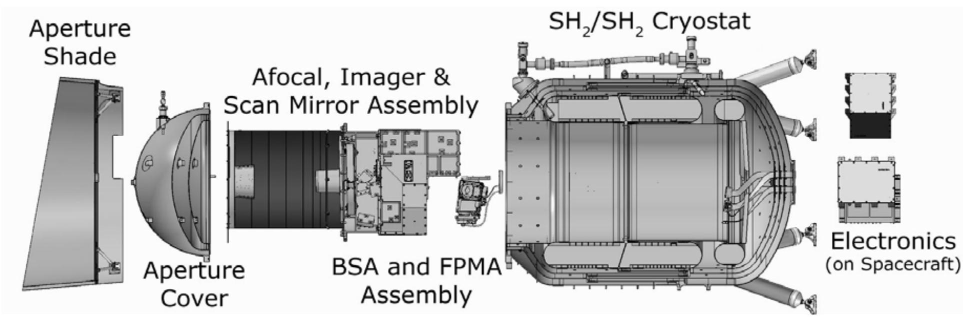

FIGURE 1. WISE Instrument Configuration

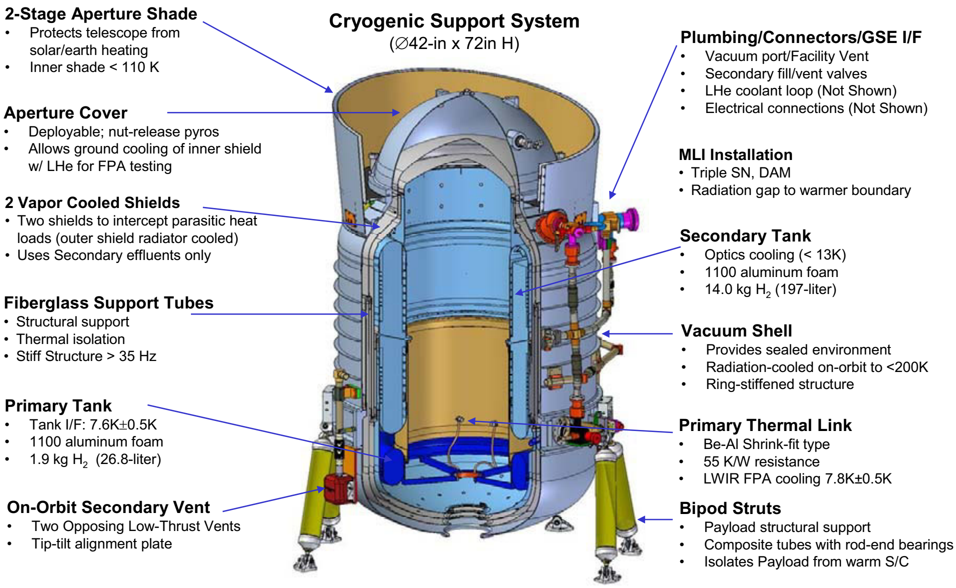

FIGURE 2. WISE Cryogenic Support System Features

The WISE instrument is thermally isolated from the spacecraft. The thermal isolation allows the outer shell to be passively cooled to < 200 K on orbit to limit parasitic heat loads into the solid hydrogen. Four fiberglass bipod strut assemblies support the instrument off the spacecraft, providing the necessary launch support for the instrument and necessary thermal isolation.

Table 1. Cryogenic Support System Performance Summary

Item	Performance	Comments
Cryogen Lifetime	Primary: 18.0-mo Secondary: 15.6-mo	Lifetime includes early mission events: shell cooldown, door removed up to 2-weeks after launch, blow-down from triple point
Cryogen Mass (Hydrogen)	Primary: 1.9 kg Secondary: 14.0 kg	
Cryogen Heat Load	Primary: 19.4 mW Secondary: 159.5 mW	Includes instrument heat loads (Primary: 18mW, Secondary: 28mW)
Cryostat Interface Temperatures	Primary: 7.5 K Secondary: 10.3 K	Secondary temperature includes ¾-inch pyro valve and low thrust vent resistances
Vacuum Shell Temperature	Hot Case: 197.9 K Cold Case: 179.1K	Orbit average hot & cold temperatures
Aperture Shade Temperature	Hot Case: 96.3 K Cold Case: 90.1 K	Orbit average hot & cold temperatures of inner shade
Temperature Stability	<<150mK/orbit	Vacuum shell perturbation has negligible effect on cryogen temperature stability
Ground Hold	82-hrs	Assume 300K ambient vacuum shell temperature with 24-hrs pre-cooling
Mass	238.3 kg	Mass driven by natural frequency and vacuum shell pressure requirements
Envelope	∅42.0 in x 72-in H	Outer cylindrical envelope

CRYOGENIC SUPPORT SYSTEM CONFIGURATION

The essential features of the WISE cryogenic support system are highlighted in Figure 2. A list of the predicted performance parameters is shown in Table 1.

Primary and Secondary Cryogen Tanks

The 26.8-liter primary tank is used exclusively to cool the two LWIR FPMAs, thus minimizing the risk in achieving and maintaining the LWIR interface temperature of 7.6K. The 197-liter secondary tank cools the telescope to an interface temperature of <13K. It also guards the primary tank, reducing parasitic heat loads into the primary to insignificant levels.

Both tanks are filled with a 1.7% dense 1100 aluminum foam heat exchanger to limit tank end-of-life (EOL) temperature drops and to make the tanks isothermal. The tank sizing is based on a 78% solid fill fraction to allow the cryogen to completely melt during ground hold without venting.

Although a full-sky survey calls for a 7-month mission, the cryostat has been designed to carry out two full-sky surveys while still meeting all operational requirements. Current lifetime calculations indicate that the cryostat can support a 15.6-month mission, with the lifetime being driven by the secondary tank.

Thermal Isolation, Vapor Cooled Shields & Vacuum Enclosure

Thermal isolation between temperature zones is provided by fiberglass tubes, silk net/double aluminized mylar multi-layer insulation (MLI), two vapor-cooled shields (VCS) (including one that is also radiation-cooled), and low conductance lead wires for the instrumentation.

The internal support tube assembly consists of the three fiberglass support tubes connecting the vacuum shell to the secondary tank. The tube fold point locations also include hardware for support of the two vapor-cooled shields (VCSs). A fourth fiberglass tube mechanically connects and thermally isolates the primary tank from the secondary tank.

The two VCSs, cooled by secondary tank effluents, reduce the parasitic heat load to the secondary cryogen. A radiator plate incorporated on the outer VCS in the aperture plane provides additional cooling at this temperature zone.

The cryostat is hermetically sealed by a ring-stiffened vacuum shell and a deployable aperture cover. The vacuum shell is locally strengthened to accommodate bosses for plumbing access and electrical connector installation, an aperture door mounting flange, and a girth ring through which the structural loads are transferred from the cryostat's internal support tube assembly to the bipod struts.

The cryostat attaches to and is isolated from the spacecraft by four pairs of bipods. The bipod struts are fiberglass tubes with monoball end fittings that provide the requisite support through launch, alignment and stability during operation, and thermal isolation from the ambient spacecraft structure.

The deployable aperture cover is a hemispherical dome that attaches to the forward section of the vacuum shell. It is mechanically attached at three locations with separation nut release and bolt catcher mechanisms. The separation nut release mechanisms are also used in conjunction with a spring-plunger assembly located on either side of the nut release mechanism for door deployment. A helium heat exchanger is attached to the cover inner shield, allowing the shield to be cooled to <20K on the ground for *in-situ* detector tests during the payload test program.

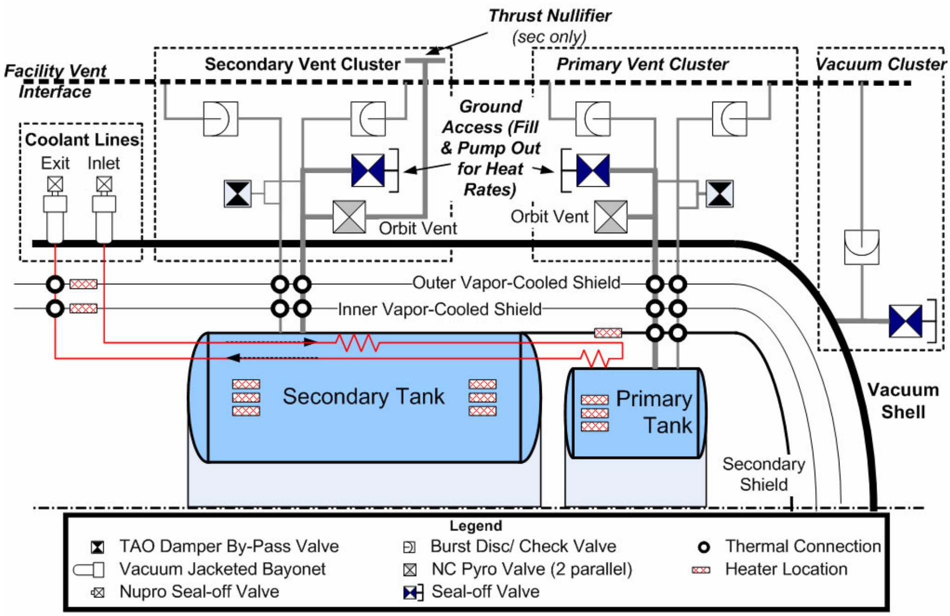

FIGURE 3. WISE cryostat plumbing schematic

Plumbing Configuration

Cryostat plumbing is required to conduct ground and orbital operations. The plumbing is grouped into four major clusters, partitioned by the principal hardware they support on the cryostat—secondary vent, primary vent, tank coolant, and vacuum clusters. A schematic of the cryostat plumbing is shown in Figure 3. The aperture cover coolant lines, not shown in Figure 3, are similar to the tank coolant penetrations.

The secondary vent cluster accommodates all ground and orbital operational requirements involving the secondary cryogen tank. During ground operations, a seal-off valve is used for both the gas fill (of para-hydrogen gas) and pumping (during testing) to stabilize temperature and measure flow rates. During launch and orbital operation, this valve remains closed and in its place, a normally-closed pyrotechnic valve is used. This pyro valve remains closed during launch, but is opened soon after spacecraft separation from the launch vehicle. Downstream of the pyrovalve are two low-thrust vent assemblies. The opposing vents reduce the resultant torque on the flight system during blowdown and anomalous venting conditions.

In parallel with the ground and orbit vent valves is a 15-psid burst disc / check valve (BD/CV) assembly, which has been sized to accommodate the flow rates for the worst case event—an unplanned loss of vacuum surrounding a loaded cryostat—while maintaining the tank pressure below design limits.

The primary vent cluster is similar to the secondary cluster, having only one notable exception. Though the primary vent lines are shown to be connected to the VCS, there is no attempt to provide a section of heat exchanger for vapor cooling. On the contrary, links are connected from the VCSs to the plumbing to control the temperature distribution within the primary vent line.

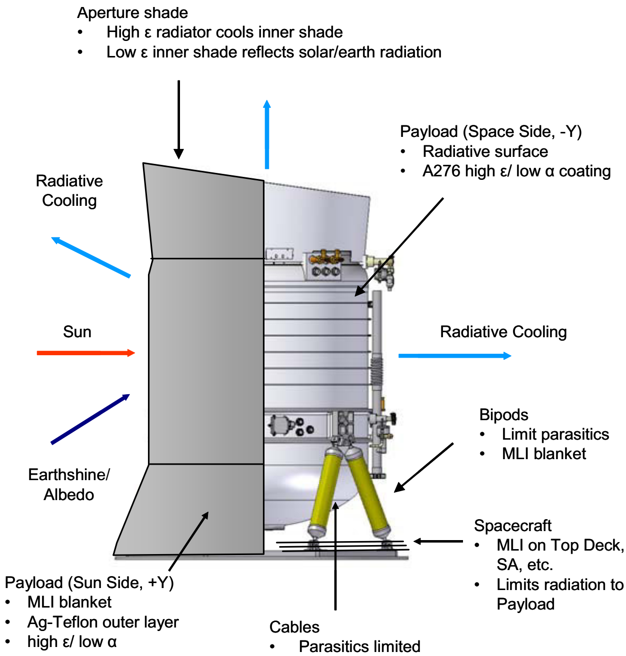

FIGURE 4. External thermal control concept

The coolant clusters on the cryostat and aperture cover are the only penetrations requiring bayonets. The cryostat coolant cluster cools both the primary and secondary tanks with liquid helium, while the aperture cover coolant cluster only cools the inner shield which is viewed by the telescope aperture.

The vacuum cluster is a relatively simple set of hardware that includes a seal-off valve for pumping on the vacuum space, and a BD/CV for protecting the shell from over-pressure. All BD/CV outlets are tied together into a single safety vent interface to allow for safe venting of hydrogen during ground operations if necessary.

Aperture Shade

The aperture shade consists of an inner and outer shade structure, thermally isolated by thin-walled fiberglass tubes and MLI. The inner shade is cooled to <110K by a small annular radiator patch lying near the plane of the telescope's entrance aperture. Shade cone angles allow tipping by up to 10-deg in the opposite direction for viewing close to the earth limb before the active radiator surface is illuminated. A specular, low emissivity gold coating on the inner surface reflects any incident earthshine away from the aperture and minimizes the shade's intrinsic thermal backload to the telescope aperture. The outer shade, which mounts to the vacuum shell, is cooled to <200K and shields the colder inner shade.

External Thermal Control & Environmental Heat Rates

Figure 4 illustrates the WISE thermal control approach. The instrument sits atop the ambient spacecraft deck, with the telescope pointing near the local zenith during surveying operations. An MLI blanket on the spacecraft top deck and the bipod assemblies provide thermal isolation between spacecraft and the colder vacuum shell.

Figure 5. Cryogenic support system hardware. (Clockwise from top left: primary and secondary tank assembly layered with MLI to inner VCS, assembled primary tank, secondary tank heat exchanger installed to the telescope interface flange, bipod assembly, aperture shade radiator, outer aperture shade, primary thermal link.)

The vacuum shell is passively cooled using MLI blanketing and thermal control surfaces. The thermal load on the sun-pointing side of the instrument is minimized by an MLI blanket having a low α/ε outer layer. The side of the vacuum shell facing away from the sun is painted with A276 white paint and provides a radiative cooling surface for reducing the vacuum shell temperature to ~200K.

CRYOGENIC SUPPORT SYSTEM STATUS

Fabrication and assembly of the cryostat support system is currently underway. The cryostat has been assembled through the installation of the outer vapor cooled shield. The vacuum shell components are being fabricated. The bipod assemblies and primary thermal link have been assembled and tested. The aperture shade component fabrication is complete and assembly is underway.

The cryostat assembly will be completed in the Fall of 2007. Environmental testing of the cryostat, which includes thermal testing with hydrogen, will be completed during the first part of 2008. Integration with the flight telescope and characterization testing will occur throughout 2008 and into the first part of 2009. This testing will include a second hydrogen test to verify the thermal performance of the cryogenic support system. The WISE instrument will be integrated with the spacecraft in the spring of 2009 with launch scheduled for November of 2009.

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