Manufacturing of Cryoshroud Surfaces for Space Simulation Chambers

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Current Activity in Space Simulation

General Description and History

Establishment of the space program in the 1950's stimulated the development of vacuum techniques and equipment. In addition, the needs to simulate the thermal environment to be encountered by spacecraft led to the refinement of methods for heating and cooling of internal surfaces to both elevated and cryogenic temperatures.

Simulation requirements for current needs have required vacuum chambers and thermal shrouds to have greater range of temperatures, more uniform environments, higher emissivity, and cleaner vacuum. In turn, this has driven manufacturers of thermal vacuum chambers to improve methods of thermal analysis, metal fabrication, leak testing, and paint application for internal surfaces.

Solar simulators capable of producing the equivalent of more than five times the intensity of sunlight in low earth orbit have also been incorporated into thermal vacuum test systems. In several large chambers, more than 1 MW of power is used to excite Xenon lamps to produce simulated sunlight. While the high intensity beams illuminate spacecraft under test, they also add significantly to the heat loads that thermal shrouds must cope with.

As in all engineering projects, a balance or performance, cost, and schedule must be achieved in the design and fabrication of shroud systems. The continued use of systems now nearing 50 years old reminds us that design and construction must remain focused on delivering usable performance over the long term. Cleanliness, low outgassing rates, temperature control, and stabile properties of thermal surfaces are key aspects in long-term operation of new systems and for upgrades to performance of existing systems.

Small Systems

Testing of small components and subsystems may be done in very small vacuum chambers. Even at reduced scale, it is still possible to have a controlled thermal environment as well as high vacuum. Platens cooled by liquid or gaseous nitrogen or by closed-loop chillers offer way to create a variable temperature condition.

Typical of a small lab system with LN_2-cooled platen is the chamber shown below. In this case, the chamber liner is used to promote temperature uniformity but does not have a high emissivity coating.

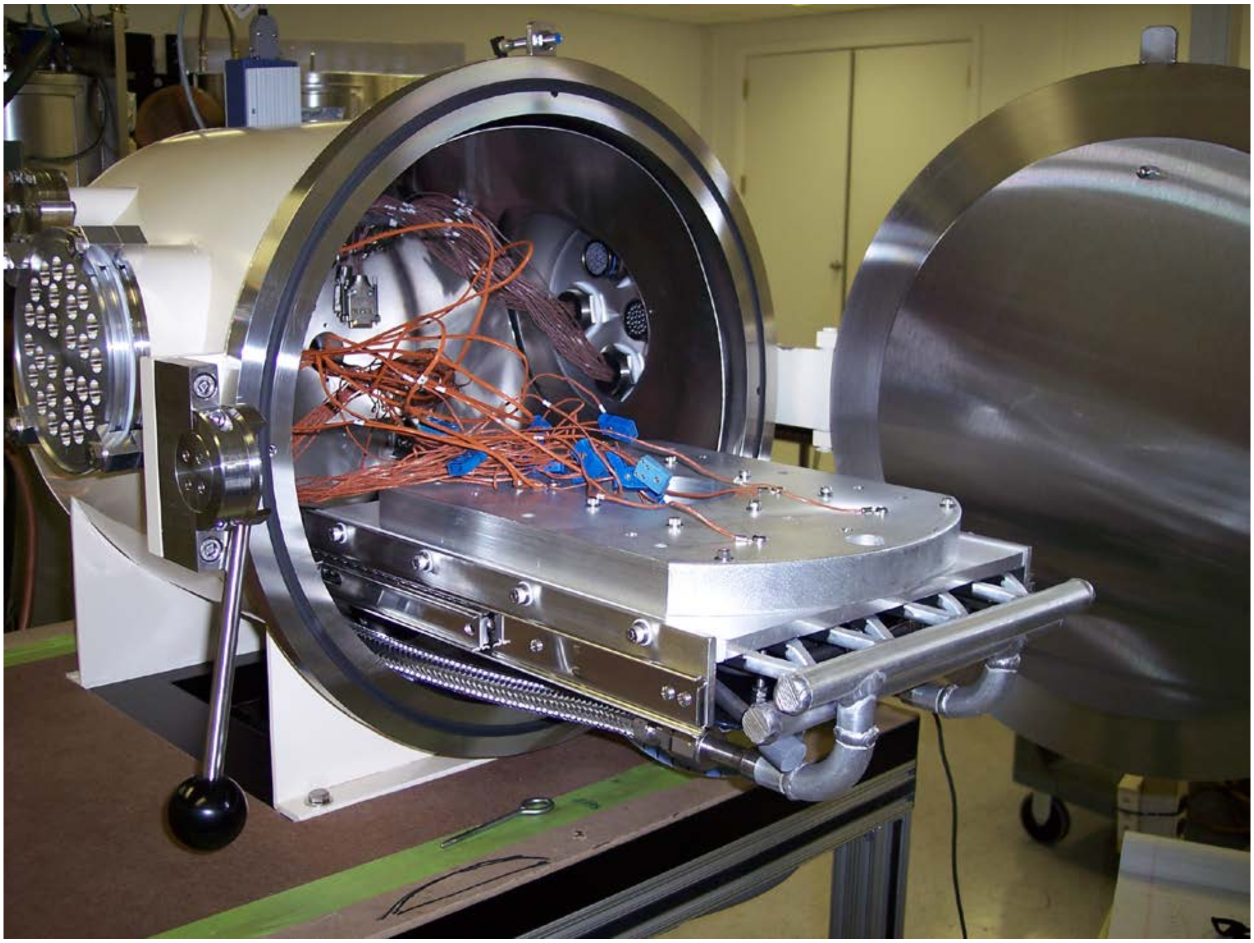


Figure 1: Small thermal vacuum system.

Large Thermal Vacuum Systems

At the opposite end of the scale, large systems must accommodate full satellite or spacecraft articles in the desired thermal environment. While more difficult to fabricate, the same range of technical challenges and solutions applies.

Figure 2: A shroud for operation over the -150 °C to +150 °C with gaseous nitrogen in a 17 ft diameter chamber.

JWST

Construction of the James Web Space Telescope and a rigorous scheduled test program have necessitated reviews and upgrades to a number of very large vacuum chambers in the U.S., both at NASA facilities and major aerospace contractors. The main mirror is 6.6 m diameter and is mounted on the side of the observatory facing away from the sun. The full observatory will weigh more than 6500 kg and will use a sunshield measuring 12 x 22 meters to obtain operating temperatures near 40 K. Subsystems will need to be fully tested before assembly, and the complete vehicle and optical assembly must also be checked out in vacuum in a well-regulated thermal environment.

Some of the requirements of the JWST test program highlight the current capabilities in thermal vacuum testing and shroud construction. Shrouds for chambers at NASA's Goddard Space Flight Center in Maryland and Johnson Space Center in Houston are to operate at LN_2

temperature and at 20 K while exhibiting high absorptance for radiation from 30-40K surfaces of the spacecraft. Some of the shroud assemblies will be installed in JSC's Chamber A, a 65 ft diameter chamber that is 120 ft tall. Others will go to chambers in contractor facilities.

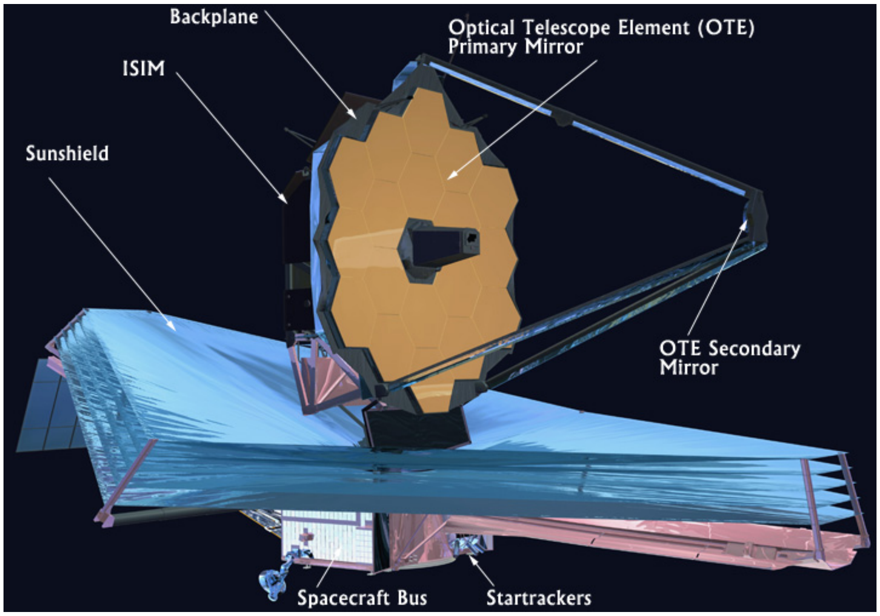


Figure 3: JWST components (NASA image)

Figure 4: Components of a very large shroud for testing components of JWST. The completed shroud structure will stand 35 ft tall and is 26 ft in diameter; interior surfaces will be painted black. This shroud will uses recirculating gaseous helium to obtain temperatures approaching 20 K.

Shroud Functions

Intercept Room Temperature Radiation

A basic function of the shroud is to isolate the test article from thermal radiation of the outside environment. Vacuum chamber walls typically run at room temperature. Under some test conditions, such as a shroud at elevated temperature, the chamber wall itself may need to be water-cooled. When the shroud is cooled, thermal radiation from the chamber wall places a heat load on the shroud.

The exterior surface of the shroud is usually reflective of infrared radiation. This is achieved by using polished aluminum or stainless steel sheet to form the shroud. With an emissivity in the 0.02-0.05 range, clean aluminum absorbs little heat from an exterior chamber wall. The use of cryogenic high vacuum pumps on systems enables the shrouds to maintain this low absorptivity over many years without cleaning or other maintenance. However, test articles which have high outgassing loads may ultimately add contamination to the shroud surfaces, resulting in higher heat loads. Design of the shroud and cooling systems takes these long-term effects into account to be sure there is sufficient cooling capacity available under all conditions.

Figure 5: An LN_2 and GHe shroud set for high precision simulation.

Vacuum Conductance and Densing

While the shroud must enclose the test article and isolate it from external thermal radiation, it must also allow outgassing from the test article to reach the vacuum pumps. Typically, louver or chevron baffles are used over openings in the shrouds to enable sufficient gas conduction, though the baffle surfaces must block thermal radiation.

Figure 6: Optical densing in a large shroud allows vacuum conductance.

Openings in the shroud for the introduction of electrical cables, optical stimulation, and other experimental functions may also alter the thermal environment. Shrouds may be designed with removable port covers which normally operate near the shroud control temperature. These covers may be removed as needed for specific experiments.

High ε/High α for Cooling/Heating Load

The internal surfaces of shrouds are typically coated with a black paint to obtain high absorptivity (α) and high emissivity (ε) to obtain good heat transfer by radiation. While emissivity and absorptivity are nominally equal when temperatures are the same for the shroud and test article, they may be very different under some conditions. A “solar absorptance” rating for a paint is heavily weighted for the short wavelength radiation of the nominal 6000 K temperature of the sun’s surface. When working with test articles having temperatures in the 40-400K range, our concern is more with paint properties in the 5-50 micron wavelength range and beyond. These properties are controlled by the pigments and binders used in the paints and by the thickness of the coating.

While reflectance measurements using a spectrometer, reflectometer, or integrating sphere is useful for obtaining and e values for objects at room temperature, calorimetric measurements are needed for precise measurement of these values at low temperatures. There are few facilities in the world capable of making these measurements, though the Contamination and Coatings Branch at NASA Goddard has continued to make these measurements and publish the thermal data, as well as outgassing rate data. Much of this data, as well as theoretical discussion, is contained in Lon Kauder's "Spacecraft Thermal Control Coatings References", NASA/TP-2005-212792.

Methods for Heating and Cooling Shrouds

Heat Transfer Liquids

For shrouds that operate over a limited temperature excursion from room temperature, use of heat transfer fluids such as silicone oils may be appropriate. These fluids may be heated or cooled by an external heater/chiller and pumped through the shroud tubing. The increasing viscosity of these fluids limits the lowest temperatures to about -70 °C. The high end is limited by the boiling or decomposition temperatures of the fluids, but typical high limit is 100-150 °C. Such systems have the advantage of uniform, controlled temperatures generated by closed-loop systems which may handle kilowatts of heat. Fairly rapid changes in temperature – both up and down – may be achieved by minimizing thermal mass of the shroud.

Gaseous Nitrogen

For wider temperature ranges, such as -180 °C to +150 °C, gaseous nitrogen (GN_2) recirculation systems are used. Pressure of the gas circulation loop is adjusted as a function of temperature to maintain constant gas density. Because gas has lower heat capacity than liquids, a large volume of gas must be circulated by a powerful blower to add or remove heat from the shroud and test article. Tubes and headers need to be larger than for shrouds using liquids.

Use of gaseous nitrogen also has the advantage that, in the event of a leak in the shroud, only clean gas will be vented into the vacuum chamber.

Liquid Nitrogen

For temperatures below -180 °C (93 K), liquid nitrogen is used. A supply header fills the shroud tubing to create uniform temperatures over the shroud. In larger systems, pumps for the cryogenic liquid may be needed to produce sufficient flow for cooling high loads.

Gaseous Helium

Temperatures below 77 K are obtained by circulating helium gas (GHe) from a special refrigeration plant, such as is used in large helium liquefier systems. A kilowatt or more of net capacity at 20 K can be obtained in this way. The refrigeration plant also serves to push the gas through the shroud piping. Vacuum jacketed lines external to the chamber are required to minimize heat losses.

Cryopumping Surface

When operating at temperatures of 150 K and below, shroud surfaces act as very efficient pumps for water vapor and other high molecular weight vapors. Since both the inner and outer surface of the shroud can condense water, each square meter of shroud surface can contribute in excess of 250,000 liter/second of pumping speed. Since water vapor is the major gas load in most vacuum systems, the cold shroud accounts for most of the high vacuum pumping, even when multiple large cryopumps are used.

It should be noted that anything outgassed by the test article is likely to be condensed on the cryogenic shroud surfaces. Strict attention to the use of instrumentation wiring with Teflon insulation as opposed to PVC prevents contamination of chamber and shroud surfaces with plasticizers and other unwanted materials.

Design and Analysis Methods

Design of shroud surfaces begins with the definition of operating temperature range, ramp rates to be obtained, and total heat load to be added or removed. Normally, a uniform heat load is assumed over the interior surface of a cooled shroud, and the shell thickness and cooling tube spacing can then be derived from the fin equation. The solution of the differential equation which assumes the warmest areas are midway between two cooling tubes yields the temperature profile across the surface. Cooling medium mass flow, heat capacity, and viscosity then determine the diameter and spacing of cooling tubes required.

A basic condition is that there must always be a temperature gradient from the interior of the fluid flow through the tube to the shroud surface, as well as a gradient along the direction of flow. It is this temperature gradient that forces the flow of heat. Calculated results are compared to system specifications to iterate to a set of values for tube sizes and placement.

Most of these calculations can be done with spreadsheet models which incorporate all of the flow conditions and thermal properties. Since a complete chamber may consist of a set of shrouds for the main cylindrical wall, two end caps, and various penetrations, fluid flows must be balanced to get uniform temperatures in all areas. Finite element analysis may be required in shrouds of more complex shapes or with many penetrations that force tubes to be moved from optimum positions. Building accurate mathematical models as part of the design activity can be a lengthy process, but is necessary before cutting metal.

A heating system is supplied on some cryogenic shrouds to enable a rapid return to ambient temperature before venting the chamber. To minimize thermal shock on massive test articles, shrouds may need to be heated according to a programmed temperature ramp for return to ambient temperature. Local hot spots must be avoided so indirect radiant heating is sometimes used on the outer shroud surfaces. The control system to follow specified ramp rates adds to the complexity of space simulation systems.

Structural needs for supporting test loads or people during loading of the chamber may force the use of heavy aluminum beams or channels to maintain the shape of the shroud. These become part of the entire thermal mass which must be heated and cooled.

Verification of design predictions and process monitoring is provided by an array of temperature sensors mounted to shroud surfaces at various locations. For elevated temperatures and cooled surfaces to 77 K, thermocouples provide sufficient accuracy and resolution. At lower temperatures, silicon diodes are preferred as sensors because they provide high signal levels at relatively low impedance.

Shroud Materials

Aluminum

Both 6061 and 1100 aluminum alloys are typically used for construction of cryoshrouds. Alloys in the 5000 series are also used. For temperatures of 77 K and higher, the thermal conductivity of the 6061 alloy is adequate and the mechanical strength is higher. For shrouds for use in the 4-50 K range, 1100 alloy is used for its better thermal conductivity, though structural elements normally remain as 6061 because of its better strength.

Typical sheet thickness is 1/16 inch or 1/8 inch. This provides sufficient conductivity with the lowest practical mass. Cryoshrouds are rigid enough to maintain their shape but are not normally intended to carry structural loads. Where mechanical load carrying capacity is required, I-beams or other structural shapes in aluminum are used as part of the shroud.

Stainless and Copper

Shrouds may be constructed of type 304 stainless steel for gaseous or liquid nitrogen use. In some cases, dimpled or stamped channel, double-wall construction is used to direct liquid or gas flow within the shroud. While stainless steel shrouds are more common in Europe and Asia, there are no specific technical reasons to choose stainless steel over aluminum. Similarly, while copper has higher thermal conductivity than aluminum, cost and fabrication difficulties dictate against the use of copper as a shroud material.

Other

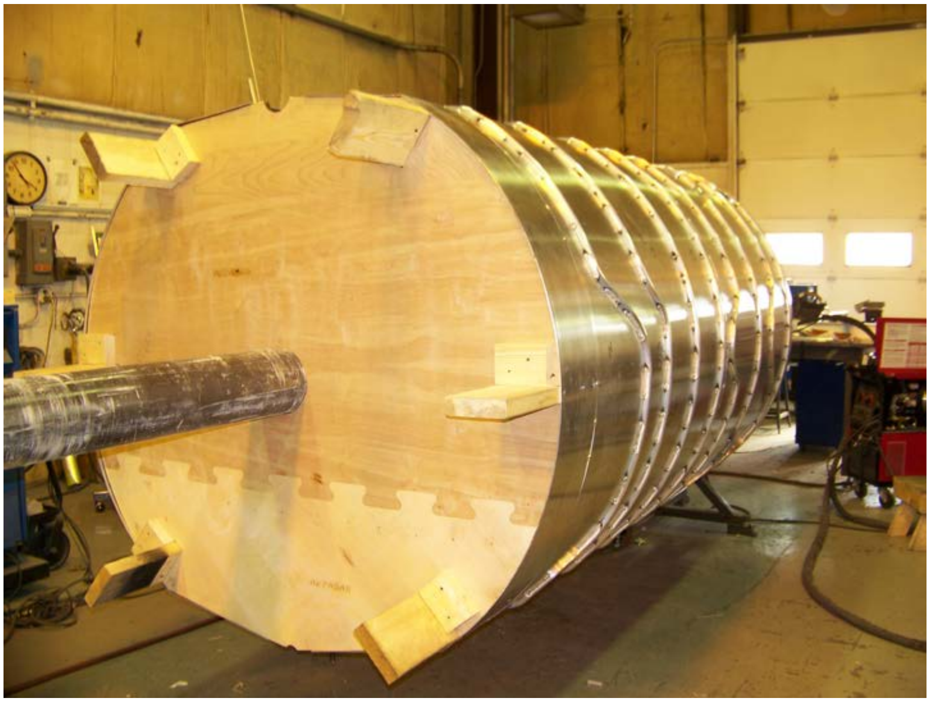
Thermal insulators are needed at points where the mass of the shroud must be supported without heat leaks from the vacuum chamber structure. Thick “donuts” of PTFE or nylon are commonly used. For tensile loads, glass-reinforced epoxy laminate, such as G-10, are used.

Fabrication Techniques

Formed Sheet and Plate

Most shrouds have a cylindrical or “mailbox” shape. Flat sheets of aluminum are formed on a large slip roll where small radii are needed. In many cases, the radius is large and the sheets may be draped over a steel or wooden buck to meet the shape.

Recently, cycle time has been reduced and precision improved by using forms made from laser-cut plywood sheet. Sheets as large as 5x10 ft may be rapidly cut to a precision better than 0.01 inch. Very large forms are constructed by joining multiple sheets using "jig-saw puzzle" tabs and sockets.



Aluminum sheets are welded together on the form and then cooling tubes are attached by TIG welding.

D-tubes

Thermal conduction of clamped or bolted joints is poor in vacuum. Consequently, all tubes for gases or liquids used for heating and cooling are welded to the shroud sheet. Conduction from tube to the sheet is enhanced by using D-shaped tubing which provides additional metal area to form a weld. Numerous welded joints are required are required between tube sections and connectors, necessitating high quality weld techniques and precision leak testing.

Headers

Cooling fluids, whether gas or liquid, must be distributed to the various segments of the shroud surfaces in a way that transfers heat at rates needed to obtain uniform temperatures. For gases and non-boiling fluids, the headers may be located on the shroud anywhere proper distribution can be obtained. Systems using LN_2 require liquid supply headers at the bottom of the shroud and large return headers at the top for both gas and liquid

Figure 7: Small LN_2 shroud with headers attached.

Piping

External piping for gases or liquids circulating through the shroud need to be insulated. Foam insulation is adequate over the -70 °C to +75 °C range and can also be used for some LN_2 lines when runs are short and some losses are acceptable. Vacuum-jacketed (VJ) lines are needed for longer runs, large systems, and for especially for GHe circulation at low temperatures. The higher initial cost for VJ piping is balanced by lower long-term operating costs.

Flexible Lines

Often, access to the test volume is by opening a hinged door to the vacuum chamber, and this may include moving one or more of the shroud elements. A shroud cap with overlapping surfaces for optical blocking is typically fitted with flexible lines to allow movement. While these lines may be bent in a single plane, they do not allow twist. Sizing of the chamber and shroud need to include allowances for minimum radius bends of these flex lines and for controlling their motion with scraping shroud or chamber surfaces.

Leak Testing and Thermal Cycles

Over the lifetime of the chamber, hundreds of thermal cycles from room temperature to cryogenic or elevated temperatures may occur. This places stresses on the shroud components and may cause leaks if welding is not done correctly. Generally, shrouds are thermally cycled during construction and acceptance testing followed by helium leak testing to assure vacuum integrity of the system.

Paints

Most shrouds are painted black on the inside to enhance thermal exchange with the test article through radiant heat transfer. In some test scenarios, low optical reflectance is also a requirement. Generally, a flat black is used which is compatible with the temperature and vacuum ranges required in the system. Other factors may also play a role in the selection of the paint.

Outgassing of cured paints must be held to a low value to meet requirements for vacuum levels and to maintain cleanliness of the test articles. NASA uses a standard test technique to measure total mass loss (TML), collected volatile condensable material (CVCM), and water vapor regained (WVR) during 24 hours at room temperature and 50% humidity. Paints with TML <1% and CVCM <0.1% are considered for use in vacuum. For many paints, the WVR value will be close to the TML value, indicating that the mass lost by baking the paint at 125°C during the test is mostly absorbed water as opposed to residual solvents. Test method details and results for many materials are available on the http://outgassing.nasa.gov website.

Shrouds much larger than the size of a car or truck encounter several difficulties in the painting process. Large paint booths are needed so that the application is done in a controlled environment. Increased regulation activity by OSHA, EPA, and local authorities requires control over solvent use, application procedures, and equipment used for personnel protection. Paint application to meet these standards has become an increasingly complex process. None of these paints should be used without specialized equipment and training.

Paint Thickness Requirements

Emissivity properties of most paints are dependent on having a sufficient dry film thickness. This may range from 1-2 mils (.001-.002 inch) up to 6 mils or more. However, overly thick films may be subject to adhesion failures.

Thickness control is normally obtained by use of a comb-type wet film thickness gauge. A typical paint may require a wet film thickness of .005 inch to obtain a dry film thickness of .0011 inch due to solvent evaporation. To obtain a thicker dry film, two or more wet coats may need to be applied, spaced by a drying period of 3 to 24 hours. Completely cured films may need scuffing over the entire surface to obtain adhesion for a second coat. Both access and the generation of dust dictate that sanding and scuffing should be avoided. This emphasizes the need for tight process control on the application cycle.

Paint films must be thick enough to have incident radiation from the test article, solar simulator illumination, or other optical stimuli fully absorbed by the pigment and binder to avoid reflections from the underlying metal surface. Similarly, the paint materials must be applied in sufficient thickness to fully reach the potential emissivity at the operating temperature of the shroud.

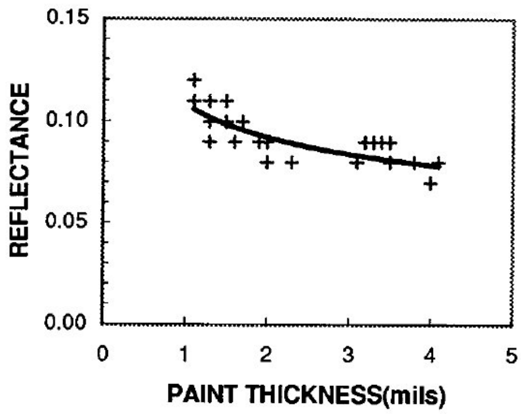


Figure 8: Reflectance of Z306 paint versus thickness. (From M.J. Persky, "Review of Black Surfaces for space-borne infrared systems", 1999)

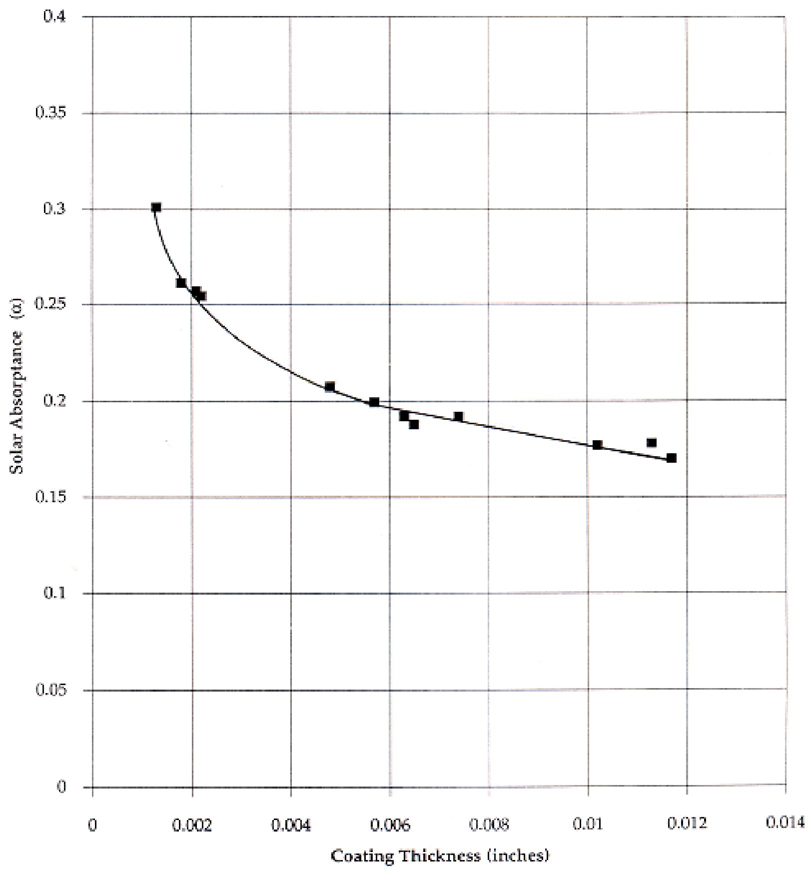


Figure 9: Solar absorptance of a white silicone paint (L. Kauder, "Spacecraft Thermal Control Coatings Reference", NASA 2005).

Dry film thickness may be verified by the use of eddy current gauges on aluminum panels or by magnetic sensors on steel panels. This is a non-destructive measurement method which uses a relatively inexpensive instrument. Checks of thickness at a number of points on a shroud help to confirm that thermal properties will be met on all areas of the surface.

Figure 10: Coating thickness gauge

Durability

Cured paints for thermal shrouds produce a stable, tough coating which will withstand many years of use. Temperature cycling over extreme ranges, exposure to humidity, water, and a variety of other fluids will not normally affect a well-prepared surface.

Paint processes are usually qualified by a series of durability tests. Testing verifies that both the surface cleaning and paint application procedures can produce the required results. Among the tests that are frequently performed to qualify the process are:

- Scotch tape adhesion, both on smooth painted surfaces and on painted surfaces which have been scored in an "X" pattern with a sharp tool.
- Mandrel bend tests around 180° of a rod with a diameter of ¼ to 1 inch.
- Temperature/humidity cycling.

Repairs to Painted Surfaces

In spite of a high level of attention to test chamber operations, damage to shroud painted surfaces may occur, either through mechanical damage or the use of an ion thruster in a chamber. Additionally, chambers and shrouds may get modified over time. In planning a new chamber or major overhaul, methods need to be considered for repair of small areas and also for completely repainting the shroud.

With the urethane-based paints, a second coat may not adhere to a completely-cured first coat unless the surface is scuffed. It may even be necessary to strip finish paint and primer to bare metal, reprime and repaint. Small areas may be stripped with an abrasive wheel and retouched with paint applied by a brush. While this can work for urethanes which air cure in a few days at room temperature, repairs become less practical on silicone-based paints that require baking at 300 °F or more to obtain complete cures and low outgassing rates.

Some Properties of Specific Paints

There are many families of paints that have been used for painted surfaces in vacuum chambers. They are selected for any specific application based on several characteristics:

- Emissivity/absorptivity values
- Temperature range to be used
- Outgassing rate
- Ease of application and cure cycle
- OSHA/EPA requirements
- Cost

Several paints are described below because they are commonly used in space simulation systems. There are many other paints which have also been used with good results, as well as other types of surface treatments. The ones described here have shown to be useful on large areas with complex shapes, have acceptable costs, and may be reproducibly applied in an industrial manufacturing environment.

Z306/Z307

Aeroglaze Z306 Flat Black Absorptive polyurethane is a single-component paint that offers all-around excellent performance for many cryogenic shroud applications. Its solar absorptance is 0.96-0.97 and its emissivity is 0.89-0.91 at 290 K. It has very low outgassing rates in vacuum. This paint is made by Lord Corporation. Previously known as Chemglaze Z306, the paint has been used for more than 30 years for painting the exterior of aircraft, as well as for space applications and thermal vacuum test chambers.

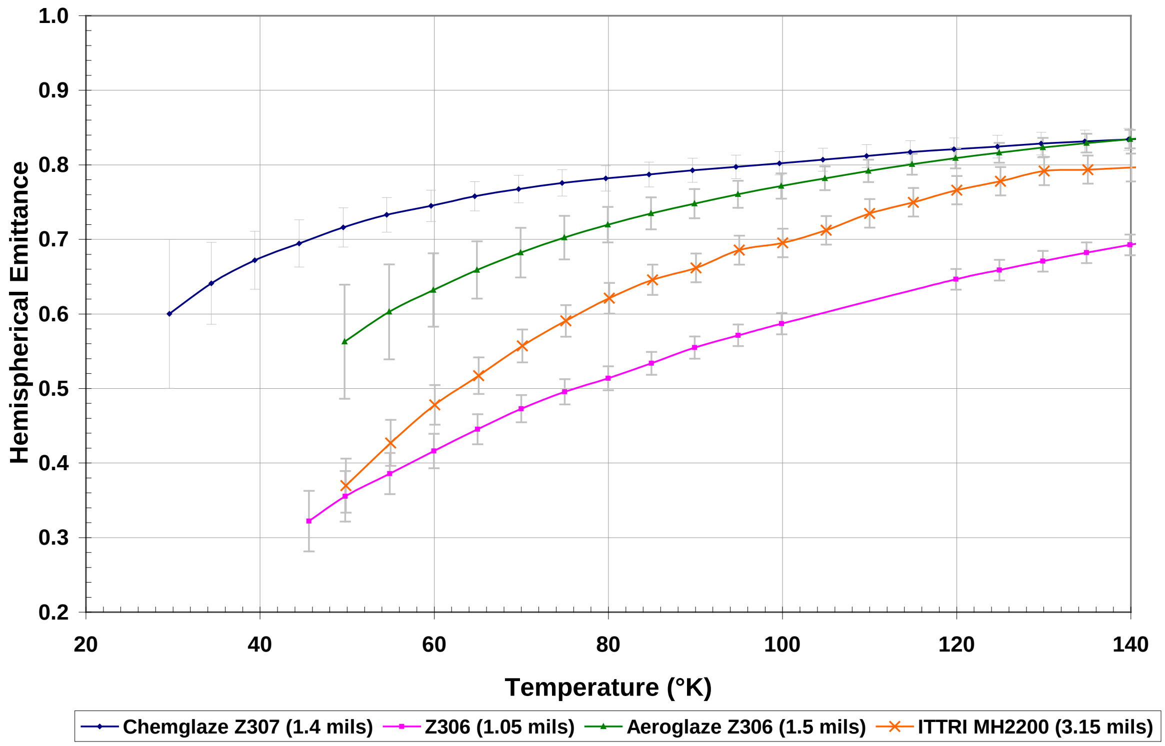
When applied to aluminum shrouds, a thin proprietary primer coat must be applied and allowed to dry completely. Failure to use the recommended primer and application procedure may result in adhesion failures during thermal cycling. Once primed, there is no specified limit on the time before finish painting with Z306. This is not true for some other paint/primer combinations.

Curing of Z306 occurs by evaporation of the solvent carriers and thinners and by incorporation of humidity in air over a period of a few days to a week at room temperature. Unlike other paints, the cure is NOT accelerated by elevated temperatures or vacuum baking. While a small amount of water is held by the cured paint and is outgassed during a vacuum pumpdown cycle, no significant amount of other solvents is released by pumping or mild heating.

It is important to note that Z306 and related urethane paints are rated for continuous use at temperatures up to 150°F (65°C). NASA outgassing tests are performed at this temperature. At higher temperatures, the paint begins to decompose, so optical properties as well as mechanical properties may be compromised by heating shrouds above this temperature, though no published data exists on these effects. However, a number of users have reported extended use at temperatures well above 65°C.

Z307 is a related paint composition that includes the addition of fine carbon black to obtain electrical conductivity for static charge control. Optical and thermal properties are equivalent to Z306.

Emittance Data of Various Vacuum-Rated Black Paints at Low Temperatures
Courtesy of Lon Kauder, Goddard Space Flight Center, Greenbelt, MD



A276 White

Aeroglaze A276 white urethane is a low solar absorptance of about 0.20-0.25 and high 290 K emissivity of about 0.9. It has essentially the same application procedure and mechanical properties as the Z306 black paint. It is useful where different visual and IR optical properties are needed, and is also useful as a general vacuum-compatible paint.

MH2200

As with the other common black paints used for shrouds, MH2200 has a long history with different names under different manufacturers. It was known as ECP-2200 when made by 3M and MH-2200 when developed by Illinois Institute of Technology Research Institute. It is currently produced commercially by Alion Science and Technology as part of a family of black, white, and transparent thermal control coatings.

It is normally applied in .0015 to .002 inch thickness by spraying, though it does not require a primer when used on clean, acid-etched aluminum or copper. Required film thickness is obtained with a 10-minute flash dry between wet coats.

While the paint will dry in 72 hours at room temperature to allow handling, it requires an air bake at 400°F (204°C) to completely cure and drive off all of the solvent. This cure cycle may limit the applicability of the MH-2200 where other components of the shroud may not tolerate the temperature required. Additionally, repairs or touchups may not be practical on many systems.

Of all of the popular black paints, MH2200 has the highest useful temperature capability and it has been tested at 500-1000°F without apparent loss of performance. In addition to thermal vacuum chamber and spacecraft use, this paint has been frequently used for solar absorber panels exposed to the elements. Silicone and silicate based paints generally have the highest resistance to atomic oxygen, a property that may be useful in some space simulation applications.

AKZO Nobel 463-3-8 (Cat-a-lac black)

Currently produced by AKZO Nobel, the 463-3-8 formulation has been in use for many years under a variety of names and brands. It is perhaps most familiar as “Cat-a-lac Black” and was produced under the Bostik and Dexter brands. It is a two-component epoxy which can be used on a variety of surfaces. The base and hardener are mixed and thinned with solvent for spraying. The solvent flashes off and the epoxy cures.

The 463-3-8 paint also requires a proprietary primer, but the finish coat must be applied within 48 hours or sanding will be required.

Unlike the urethanes, cure may be accelerated by heat. Complete cure is obtained in 24 hours at room temperature, 2 hours at 300°F. For use at high vacuum, a ramped bake to 250°F - 300°F is recommended to force all solvent from the dried paint film. Maximum continuous service temperature is rated at 325°F (163°C).

Primers

Many of these paints require the application of special or proprietary primers before the black or white finish paint. Moreover, the primer must go onto extremely clean surfaces which are obtained with acidic wash solutions or anodizing. Many of the best primers, e.g. zinc chromate, contain hexavalent chromium, and are more difficult to obtain clearance to use. Additionally, should paints with chromate primers need to be stripped, hazardous material handling and disposal procedures need to be followed.

Anodizing and Other Metal Surface Treatments

Aluminum may be anodized by several processes to produce an oxide of controlled thickness, hardness, and permeability. The permeable oxide may be dyed and the parts are then boiled in water to close the pores and hold the dyes. However, for vacuum use, the oxide remains porous and holds water vapor to a degree that results in much higher outgassing loads than non-anodized aluminum. For this reason, both clear and dyed anodized coatings are to be avoided where possible. In addition, the black dyes are only light-absorbing in the visible and near infrared wavelengths, so they are not used for large shroud surfaces.

Other surface treatments have been considered for passivating the bare aluminum surfaces of shrouds and other chamber fittings as a method of maintaining low absorptivity over a long time period. However, even the freshly treated surfaces have emissivities much higher than are expected after many years of vacuum chamber use. Little benefit is seen in passivation coatings for bare aluminum.

Aluminum platens used to mount test articles are the most frequent items to be specified with anodizing. Because these platens tend to be for a wide range of uses and subject to frequent handling, black anodizing is sometimes preferred over paint which may be subject to chipping. A practical balance of thermal and vacuum properties versus maintenance requirements needs to be achieved in specifying surface treatments in these cases.

Summary

Shroud surfaces for thermal vacuum test chambers play an important role in obtaining precise test conditions for space simulation. Careful attention to the design of the heating/cooling methods and distribution, coupled with accurate fabrication, can provide uniform temperatures throughout the chamber. Additionally, selection and proper application of paints for thermal surfaces enhances the thermal environment while enabling good vacuum performance. These factors contribute to gaining high confidence in test results.

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