

# Lloyd's Register Guidelines: Thermal Infrared (IR) Thermography Inspections on Vessel's Constructed of Composite Materials



## 1.0 Scope:

- 1.1 The following guidelines were developed to address the minimum standards a Thermographer would need to conduct Thermal Infrared Thermography Inspections on vessels of composite construction to meet the survey requirements of Lloyd's Register Rules and Regulations for the Classification of Special Service Craft including Special Survey, Damage, Repair, and Alterations.
- 1.2 This inspection technique is also applicable to vessels outside the scope of Classification Rules such as Lifeboats, Tender boats, and other similar craft. This will include, but is not limited to, the minimum certifications required, equipment requirements, meteorological conditions, inspection procedures, and reporting.
- 1.3 Guidelines are focused on hull aspects of fiberglass reinforced (FR) and fiberglass reinforced plastic (FRP) vessels, but it could also be applicable to condition assessment and inspection of shipboard systems including electrical panels/equipment and rotating machinery on a case-by-case basis.

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## **4.0 Referenced Documents:**

- 4.1 Level I Reference Manual, Infrared Training Center (ITC).
- 4.2 Level II Infrared Thermographer Reference Manual, Infrasppection Institute.
- 4.3 Level III Infrared Thermographer Reference Manual, Infrasppection Institute.
- 4.4 Standard for Infrared Inspection of Recreational Yachts and Small Craft Constructed of Fiberglass Reinforced Plastic and Composite Materials, 2016 Edition, Infrasppection Institute ©.
- 4.5 Standards and Technical Information Reports for Small Craft, 2020-2021 Manual, American Boat and Yacht Council Incorporated (Inc.) (ABYC).
- 4.6 NFPA 302 Fire Protection Standards for Pleasure and Commercial Motor Craft, National Fire Protection Agency (NFPA).
- 4.7 Red Ensign Group Yacht Code, Part A-B, January 2019 Edition.
- 4.8 Title 33, Navigation and Navigable Waters and Title 46, Shipping, Code of Federal Regulations (CFR).
- 4.9 Modern Shipbuilding Terms, Defined and Illustrated, F. Forest Pease, copyright 1918, J.B. Lippincott & Co.
- 4.10 Structural Composites, Composite Boat Builder Certification, Version 10.1.2007, American Boat and Yacht Council (ABYC).
- 4.11 Wäertsiliä, Encyclopedia of Ship Technology, Jan Babicz, Second Edition.
- 4.12 Wikipedia, Glossary of Nautical Terms.

- 4.13 International Association of Marine Investigators (IAMI), IAMI Marine Investigation Manual, July 2020 Edition ©.
- 4.14 Drawings Fabrications & Details Inc., Architectural Drawings.
- 4.15 United States Department of Labor, Occupational Safety and Health Administration (OSHA), Training Requirements in OSHA Standards, 29 CFR Part 1915 – Shipyard Employment.
- 4.16 International Life-Saving Appliance Code (LSA) Code, 2017 Edition.
- 4.17 International Convention for the Safety of Life at Sea (SOLAS) 1974/1978, Ch III Resolution MSC.81(70) - Revised Recommendation on Testing of Life-Saving Appliances - (adopted on 11 December 1998) Resolution MSC.402(96) - Requirements for Maintenance, Thorough Examination, Operational Testing, Overhaul and Repair of Lifeboats and Rescue Boats, Launching Appliances and Release Gear - (Adopted on 19 May 2016).
- 4.18 Lloyd's Register Rules and Regulations for the Classification of Special Service Craft, July 2020 Part 1, Ch.2, Sect 4.4 Damages, Repairs and Alterations, Sect 4.5 Existing Service Craft and Yachts - Periodical Surveys, Part 1, Ch.3, Sect 5.6 Examination and Testing - Additional Items for Composite Craft Part 1, Ch.4, Sect. 4.6 Examination and Testing - Additional Items for Composite Yachts.
- 4.19 International Maritime Organization (IMO), MSC.1/Circ.1205/Rev.1, 26 June 2019, Revised Guidelines for Developing Operation and Maintenance Manuals for Life Boat Systems.

## 5.0 Definitions:

- 5.1 **Active Infrared Thermography** – Technique employed where the surface of the material is examined while heat flows are produced by applying an external heating or cooling source and observing the thermal pattern as the surface radiates infrared energy. Examples of active infrared thermography include solar loading, heating and cooling with airflows, pulsed energy from a laser or light sources, and energy from vibrations or ultrasonics.
- 5.2 **Amidships** – In ship and vessel construction, amidships is in the middle of the length over all (LOA).

- 5.3 **Anomaly** – An anomaly is something that deviates from what is normal, standard, or expected. Anomalies identified by a visual or thermal inspection may be caused by moisture ingress, laminate to core disbonding, laminate delamination, voids, or other latent defects or repairs.
- 5.4 **Athwartships** – At right angles to the fore and aft centerline of a vessel.
- 5.5 **Bulwarks** – Fore and Aft vertical plating directly above the upper edge of the ship side surrounding the exposed deck(s). The extension of the ship's side above the level of the weather deck (whichever deck that is exposed to the weather).
- 5.6 **Composite Materials** – Composite materials are those construction materials consisting principally of fiber reinforced plastic (FRP).<sup>1</sup>
- 5.7 **Core** – The central member of a sandwich construction to which the faces of the sandwich are attached. A channel in the mold for circulation of heat transfer media. Male part of the mold which shapes the inside of the mold.
- 5.8 **Core Sample or Coupon** – A small sample of the hull laminate taken with a two (2"0) diameter or greater hole saw or similar mechanical cutting device. Samples are generally sent to a lab for analysis. This is the testing process for invasive and/or destructive testing which results in additional repair work.
- 5.9 **Debond/Disbonding** – Areas of separation within or between plies in the laminates or within a bonded joint caused by contamination, improper adhesion during processing, or damaging interlaminar stresses.
- 5.10 **Delamination** – Separation of the laminate materials in a laminate, either local or covering a wide area, can occur in the curing process or subsequent life.

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<sup>1</sup> Lloyd's Register Rules and Regulations for the Classification of Special Service Craft, July 2020.

- 5.11 **Dry Laminates** – Also known as a resin starved area. A laminate containing insufficient resin for complete bonding of the reinforcement/localized area. Insufficient resin is identified by low gloss, dry spots, or fibers showing on the surface. A failure to appropriately permeate resin within the fiberglass mat/insufficient resin to fiberglass ratio, and/or resin-compromised by either below or above working temperatures.
- 5.12 **Emissivity/Emittance** – The ratio of energy emitted by an object to the energy emitted by a blackbody at the same wavelength and temperature. Emissivity values range from 0 (a mirror that reflects all energy) to 1 (a blackbody that perfectly absorbs and radiates all energy).
- 5.13 **Field of View (FOV)** – Measured in degrees. It is the specific angle that defines the largest area which can be seen by the thermal imager. A wide-angle lens will have a larger FOV than a telephoto lens, which will be much smaller.
- 5.14 **Fiber-Reinforced Plastic (FRP)** – A general term for a composite that is reinforced with cloth, mat, strands, or any other fiber form.
- 5.15 **FLIR MSX®** – A feature found on FLIR Systems thermal imagers. Multi-Spectral Dynamic Imaging (MSX®) take two images at once — one with the digital camera and one with the thermal camera and a built-in software extracts visible light details from the digital image and embosses them over the thermal images in real time. FLIR MSX® does not compromise radiometric data and enhances the clarity of the thermal images, which allows for reflections to be separated from the structural reading.
- 5.16 **Frame** – A transverse (beam to beam) structural member that gives the hull strength. Written as frames and/or transverse frames (at right angles to the keel).
- 5.17 **Gunwale** – The junction of deck and shell at top of sheer strake (the top of a side shell plating). The gunwale is the top edge of the hull of a ship or boat.
- 5.18 **Infrared Imaging Radiometer (Imaging Radiometer)** – A thermal imager capable of measuring temperature.
- 5.19 **Infrared Radiation (IR)** – A type of radiant energy that is invisible to the human eyes but can be felt as heat.

- 5.20 **Keel** – The backbone of the vessel. The central fore and aft structural member in the bottom of the hull. Sometimes projecting from the bottom of the hull to provide stability.
- 5.21 **Lamina** – A single ply or layer in a laminate made up of a series of layers (organic composite). A flat or curved surface containing unidirectional fibers or woven fibers embedded in a matrix.
- 5.22 **Laminate Schedule** – A list of the individual layers and orientation of the plies used to construct a composite part or structure and typically specifies the ounce-weight of the reinforcement and the weave style.
- 5.23 **Longitudinal** – A frame or stiffener parallel to the keel, fore and aft.
- 5.24 **Percussion Sounding** – The process of sharply striking the vessel's topsides and hull bottom with a non-marking (phenolic type) hammer or instrument and listening to the sound it produces in order to assist in identifying laminate voids, delamination, dry-laminates, laminate to core disbonding, and core degradation.
- 5.25 **Post Processing** – Technique whereby captured thermograms (Thermal Images) are later analyzed using computer software. Typical analysis techniques include adjusting for emissivity, span, atmospheric conditions, delta-t differences, reflected temperatures, and color palette selections.
- 5.26 **Qualitative Thermography** – Art and science of detecting, displaying, and recording the thermal patterns across the surface of an object.<sup>2</sup>
- 5.27 **Quantitative Thermography** - Art and science of detecting, displaying, and recording the thermal patterns and temperature across the surface of an object.<sup>3</sup>
- 5.28 **Reflected Temperature** – Any thermal radiation originating from other objects that reflect off the target you are measuring. Also known as Reflected Apparent Temperature, T-Reflected, and/or Background Temperature.
- 5.29 **Shear** – The upward curve of a vessel's longitudinal lines as viewed from the side.

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<sup>2</sup> *Infraspection Institute, Level II, Quantitative Theory and Application, 1 Course Overview, Page 19, © Infraspection Institute.*

<sup>3</sup> *Ibid.*

- 5.30 **Special Service Craft** – Service craft is any craft within the scope of the rules other than a yacht or amphibious air cushioned vehicle.<sup>4</sup>
- 5.31 **Solar Loading** – heat added to objects by the sun that is not self-generated due to a problem.
- 5.32 **Stem** – An extension of the keel at the forward end of a yacht, ship, or boat.
- 5.33 **Stern** – The rear or backend part of a yacht, ship, or boat. The stern lies opposite the bow, the foremost part of a vessel.
- 5.34 **Stringer** – Support members bonded into the vessel's hull, visually oriented parallel to the long axis of the vessel's hull. Also described as a longitudinal (parallel to the keel fore and aft).
- 5.35 **Tabbing** – A method used in FRP and marine composite vessel construction that uses strips of fiberglass cloth that are wetted out with resin to bond or secure items or structures to the interior of the vessel.
- 5.36 **Thermal Image** – Image that shows the temperature distributions of the surfaces of objects using different colors for different temperature values. Thermal Images are taken with a thermal imager.
- 5.37 **Thermal Imager** – A camera-like device capable of detecting, displaying, and recording thermal patterns across the surface of an object.
- 5.38 **Thermal Imaging** – The use of a special camera-like devices, which display thermal patterns and temperatures across the surface of an object. The image produced can detect changes in materials used and temperatures, which can assist in identifying disbonding and delamination from heat loss and moisture ingress.
- 5.39 **Thermal Tuning** – Adjusting the range, span, and level of a Thermal Imager in order to optimize the image for analysis and/or presentation.
- 5.40 **Thermogram** – A recorded visual image that maps the apparent thermal pattern of an object or scene into a corresponding contrast or color pattern. A graphic or visual record produced by thermography.

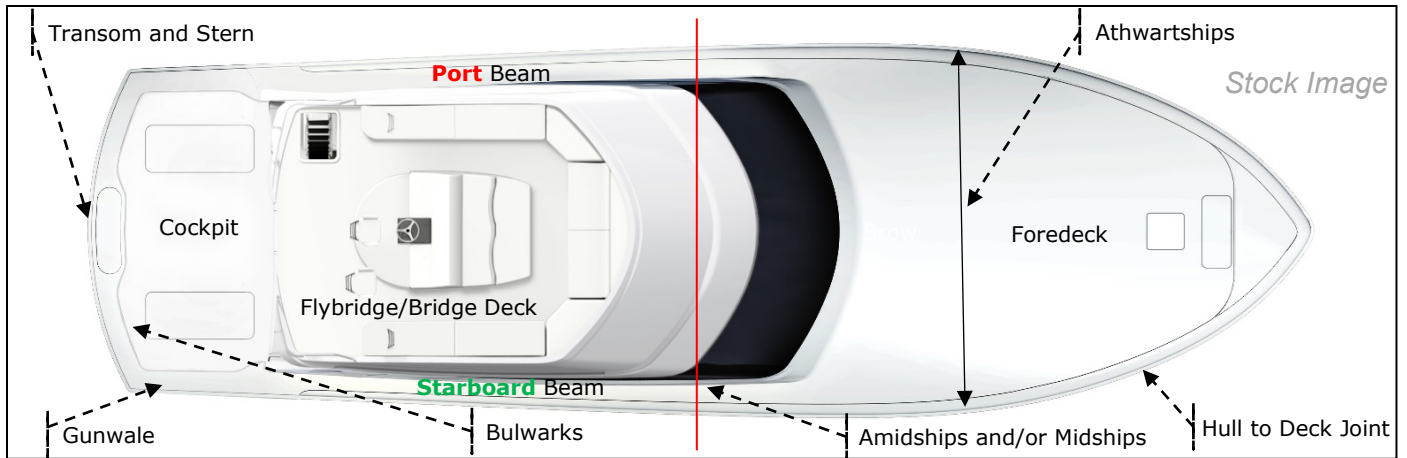
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<sup>4</sup> Lloyd's Register Rules and Regulations for the Classification of Special Service Craft, July 2020.

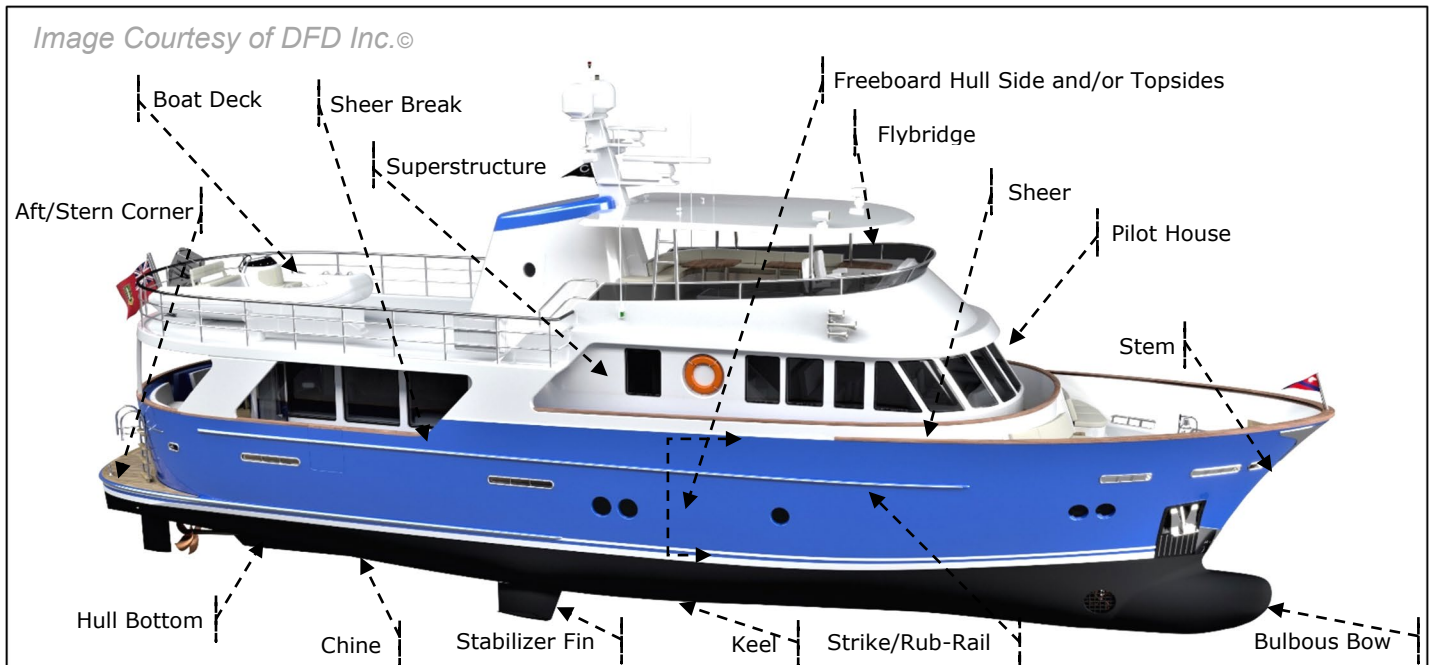
- 5.41 **Thermography** – The process of acquisition and analysis of thermal information from non-contact thermal imaging devices.
- 5.42 **Topsides** – The area of the hull of a vessel between the waterline and the gunwale.
- 5.43 **Transmittance** – The ability of a material to allow infrared radiation to pass through it (transmit).
- 5.44 **Transom** – A more or less flat surface across the stern (back or aft-most part of a ship or boat) of a vessel.
- 5.45 **Transverse** – At right angles to the keel.
- 5.46 **Vessel** – Any craft designed for transportation on the water such as a ship, yacht, personal watercraft, or boat.
- 5.47 **Voids** – Air or gas that has been trapped and cured into the laminate. Porosity is an aggregation of microvoids. Voids are essentially incapable of transmitting structural stresses or nonradiative energy fields.

## 6.0 Basic Vessel Descriptions:

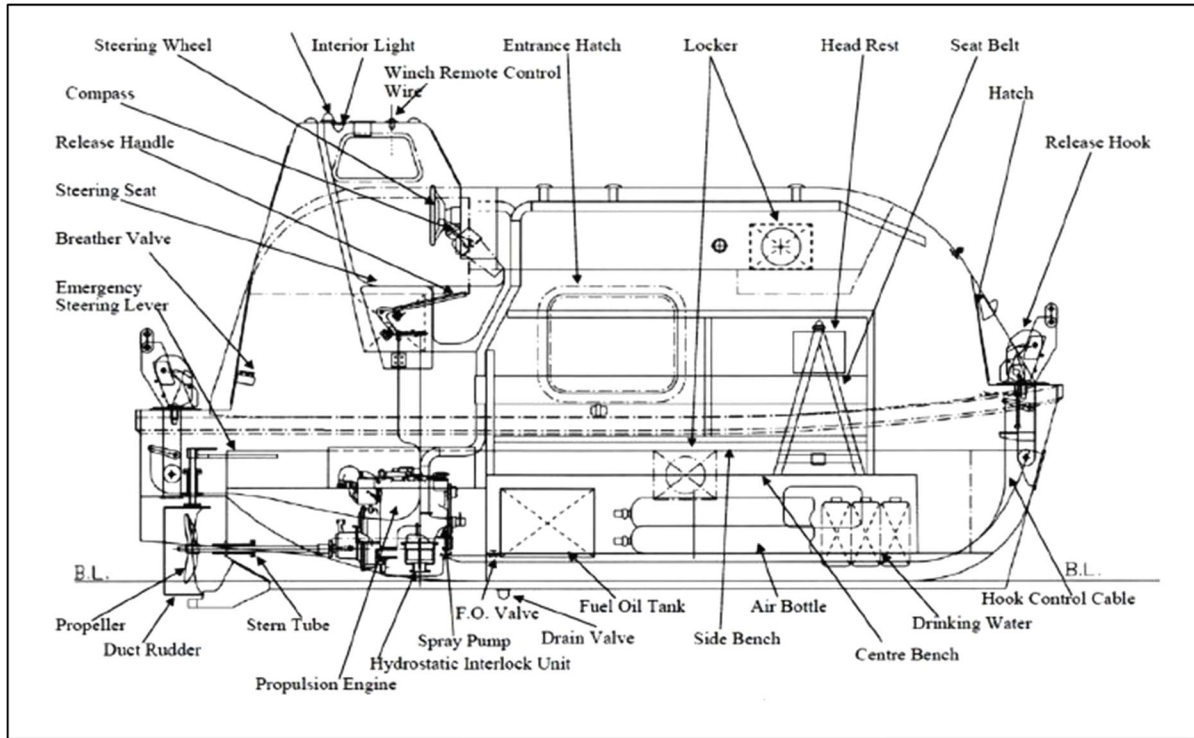
### 6.1 Aerial View: Yacht



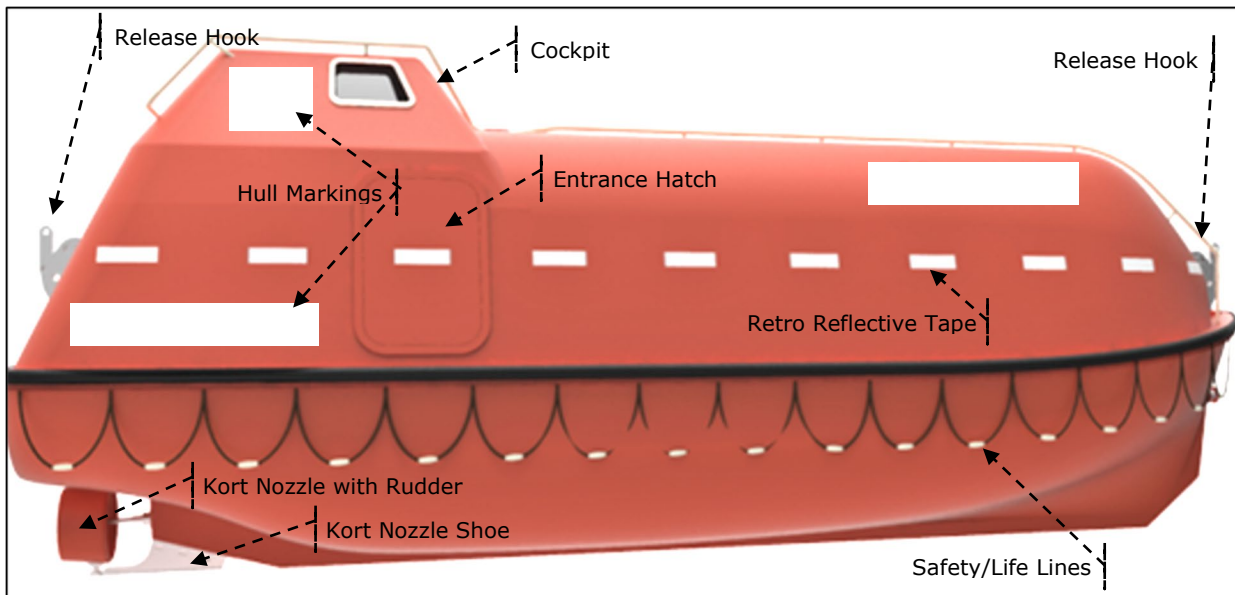
### 6.2 Side View: Yacht



### 6.3 Side View: Life Boat



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<sup>5</sup> IMO, MSC.1/Circ.1205/Rev.1, 26 June 2019, Annex. Page 9.

## 7.0 Ship/Boat Yard Requirements:

- 7.1. Prior to any inspection, all requirements must be met to enter the facility.
- 7.2. This would include all insurance requirements, any required a TWIC – Transportation Worker Identification Credential, any required personal protective equipment (PPE), and within the United States of America, any Occupational and Health Administration (OSHA) requirements or certifications.
- 7.3. The vessel must be dry-docked and blocked with keel blocks and stands.
- 7.4. It is preferred that the vessel be undercover, but the thermal infrared inspection can be conducted in open air.
- 7.5. A minimum distance of 10 to 15 feet or the width of the travel lift, should be in circumference of the vessel.
- 7.6. Prior to any inspection, a visual inspection of the areas in circumference of the vessel should be conducted to insure and to isolate any potentially dangerous hazards and/or obstructions making the inspection difficult.
- 7.7. All sub-contacted work should be terminated the day of the visual and thermal infrared inspections.

## 8.0 Thermographer Certifications:

- 8.1 The infrared thermographer should have a training level and certification of III (three), worded *Certified Level III Infrared Thermographer* and/or a designation of *Infraspection Institute Master of Thermography®*. A master thermographer is an individual who is a certified thermographer, attends technical conferences and continuing education courses, has written professional publications or articles, and has logged a minimum of 1000 hours of thermal infrared inspection time.
- 8.2 The certified infrared thermographer/inspector should be a *Certified Marine Surveyor (CMS)* or an *Accredited Marine Surveyor (AMS)* from the National Association of Marine Surveyors or Society of Accredited Marine Surveyors and/or a Naval Architect.
- 8.3 The certified infrared thermographer should have advanced and extensive knowledge of all types of marine vessels and common terminology describing a vessel and its components.

- 8.4 A certified infrared thermographer should have a working knowledge of marine drawings and construction processes and the physics of marine operations is imperative.
- 8.5 A maritime thermographer needs to have a great working knowledge of the FRP lamination process and a laminate schedule including types of lamination and the products used.
- 8.6 A certified marine thermographer should have a deep working knowledge of marine electrical and mechanical systems.
- 8.7 When using thermal imaging in an inspection, it is imperative the individual thermographer understands the principles and theory of infrared thermography and heat transfer (convection and conduction) and the in-depth science of Emissivity/Emittance, Transmittance/Transmission, and Reflected Temperature.

## 9.0 Equipment Specifications:<sup>6</sup>

- 9.1 Infrared thermal imaging systems shall detect emitted radiation and convert detected radiation to a real-time visual signal on a monitor screen. Imagery shall be monochrome or multi-color. "Non-imaging radiometers, visual infrared thermometers, and non-imaging line scanners are not sufficient." These surface temperature sensing instruments/devices have more capabilities than an infrared thermometer, but considerably less capabilities than an actual Thermal Imager.
- 9.2 Spectral Range: The infrared imaging system (Thermal Imager) shall operate within a spectral range from 2  $\mu\text{m}$  (Microns) to 14  $\mu\text{m}$  or 8  $\mu\text{m}$  to 14  $\mu\text{m}$ .
- 9.3 Spatial Resolution: Thermal Imagers must have resolution sufficient to provide clear imagery of inspected components or targets. It is recommended/required that the infrared thermal imaging system have a detector that has a minimum resolution of 464 x 348 pixels.
- 9.4 Thermal Sensitivity: For inspections that rely on active infrared thermal imaging, the Thermal Imager shall have a Noise Equivalent Temperature Difference (NETD) of 0.1 C° (100mK) or less or 30.0° C.

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<sup>6</sup> Standard for Infrared Inspection of Recreational Yachts and Small, 2016 Edition, page 9, 7.0 Instrument Requirements, Infraspection Institute©.

- 9.5 Thermal Imagers that are capable of capturing and recording thermograms on radiometric format and operate at 30 Hz or higher are preferred.
- 9.6 The selected infrared thermal imaging system must have controls that permit the operator to manually adjust level and gain of displayed thermal imagery in real time.
- 9.7 *Level and gain controls* must be able to be adjusted independently by the operator to specific temperature values. Imagers which feature only automatic gain control, commonly referred to as 'Auto Image', are not sufficient.
- 9.8 Imaging radiometers (Thermal Imagers) shall capture and store thermal images in 12-bit format.
- 9.9 Imaging radiometers which perform periodic non-uniformity corrections (NUC) of the detector are preferred.
- 9.10 Imaging radiometers should have a current factory or third-party calibration with an expiration date of no more two years before renewal or an onsite calibration using portable IR Black Body Calibrator.

## **10.0 Meteorological Conditions:**

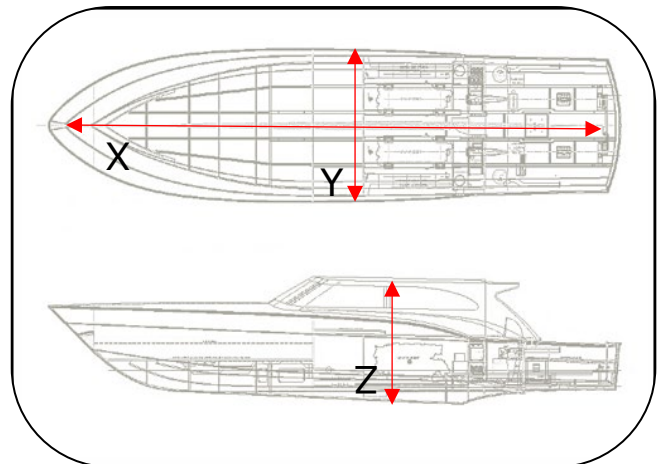
- 10.1 The vessel should be dry. No washdowns, substantial and/or measurable precipitations, dew, snow, and/or ice should have fallen or developed on the vessel during the twenty-four-hour period leading up to the thermal infrared inspection. If the vessel is located in southern climates, this can be reduced to a twelve-hour period. Windspeeds should be at or less than 15 miles per hour (MPH)<sup>7</sup>.
- 10.2 The inspection should be conducted in the evening and/or in the darkness of night time. Solar loading inspections should only be considered or used when the facility or ship yard is inaccessible after hours and/or independent heating of the vessel is not an option.

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<sup>7</sup> Standard for Infrared Inspection of Recreational Yachts and Small, 2016 Edition, page 15, 11.0 Required Conditions, Infraspection Institute©.

## 11.0 General Inspection Procedures:

- 11.1 Active Thermal Imaging inspections should follow the *Standard for Infrared Inspection of Recreational Yachts and Small Craft Constructed of FRP and Composite Materials, 2016 Edition, Infraspection Institute*®, as well as standards, codes, and regulations published by the Maritime Coast Guard Agency (MCA), The American Society for Nondestructive Testing (ASNT), American Society for Testing and Materials (ASTM International), International Organization for Standardization (ISO), Code of Federal Regulations (CFR), and Lloyd's Register Rules and Regulations for the Classification of Special Service Craft. If needed, the standard(s) should be quoted and/or referenced in the final report.
- 11.2 Prior to conducting the visual and thermal infrared inspections, an opening meeting should be made with the vessel's representative and attending Lloyd's Register surveyor. The purpose of the meeting would be to discuss the procedures and scope of inspections.
- 11.3 Upon completion of the inspection, a closing meeting to discuss the preliminary findings should be conducted with the vessel's representative and the attending Lloyd's Register surveyor. More findings may be discovered during the post processing stage of thermal imaging. The final report should be submitted to the vessel's representative and should be shared and discussed with the attending Lloyd's Register surveyor with regard to any additional findings.
- 11.4 Active Thermal Imaging Inspections in marine applications and inspections of laminates is generally done to find thermal anomalies.
- 11.5 Qualitative and Quantitative Infrared Thermography is a more informative and non-invasive inspection technique which makes it perfect for all marine inspections of all fiberglass laminates.
- 11.6 The inspector should have a base knowledge on how to lay-out a vessel using techniques such as 360° Survey and XYZ Axis with Sketch and Documentation.



- 11.7 Laying out the vessel into sections will help with identifying the exact location of the images and the areas inspected. This recommendation should also be detailed in the final report.
- 11.8 After the layout of the vessel is completed, a complete photographic documentation should follow using the "compass rose" or "box technique." Objects such as vessels should be photographed from a distance on all four sides and then additional photographs should be taken using the "box within a box" approach— from the general to the very specific.<sup>8</sup> A series of digital photographs documenting a vessel from all four sides followed by closer pictures is the preferred method. Specific deficiencies sighted in the Visual Inspection should be photographed in detail and described with specifics in the final report.
- 11.9 The thermal infrared inspection should include all of the following and/or the entire hull bottom from mid-topsides to the keel focusing on the following: rudder assembly, strut assembly (s), shaft hull penetrations, underwater exhaust, stabilizer assemblies, transducers, underwater lighting, anchor pockets, and bow/stern thruster assemblies.
- 11.10 The entire hull bottom from mid topsides to the keel should be inspected and thermal imaged for all fully cored vessel's (topsides and hull bottom are sandwich type construction).
- 11.11 For larger and multiple vessel inspections, a team may be required. The team may consist of either a Certified Level I or II Infrared Thermographer and/or a combination of the two as long as they are being overseen and instructed by a Certified Level III Infrared Thermographer and/or a Infraspection Institute Master of Thermography®.

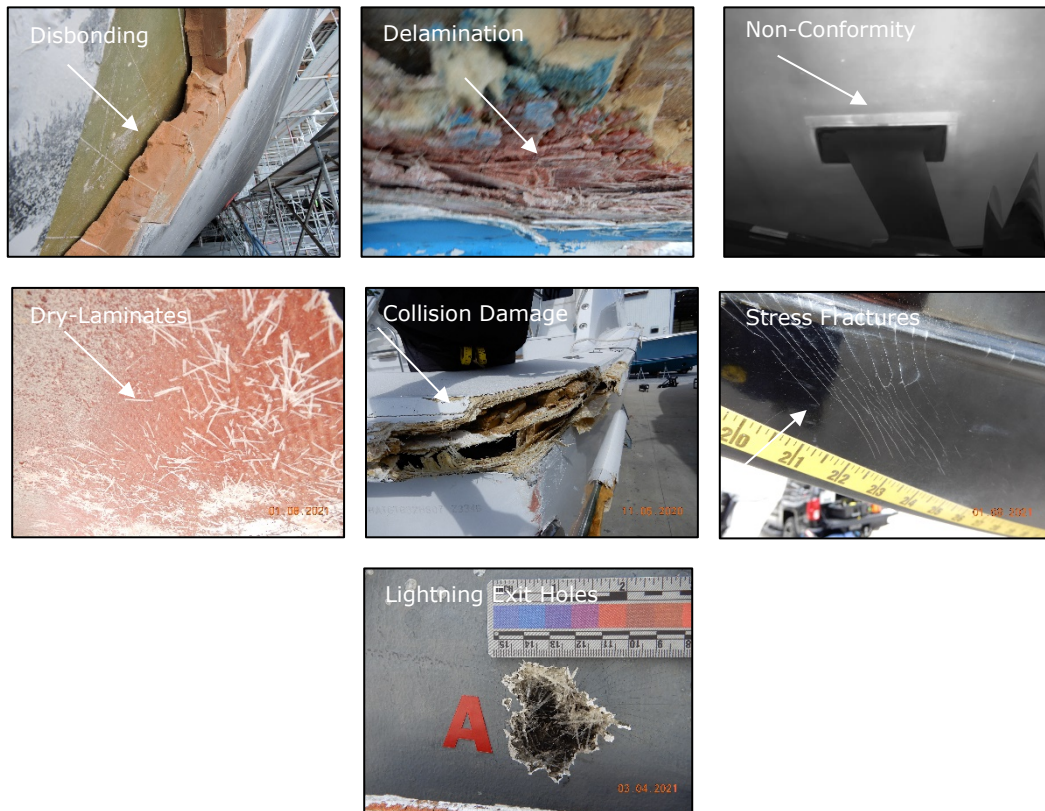
## 12.0 Visual Inspection:

- 12.1 Thermal imaging inspection should be made in conjunction with a visual inspection. The visual inspection should include a complete inspection of the areas of concern and/or all areas contracted for inspection.
- 12.2 A complete percussion sounding inspection of the entire vessel should be conducted using multiple percussion hammers (phenolic/plastic/ball peen). When sounding the topsides, care should be taken not to damage the exterior coatings.

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<sup>8</sup> IAMI Marine Investigation Manual, July 2020 Edition, Chapter 13-3, Procedures, Forensic Photography for the Field Investigator, © 2012-2020.

12.3 The areas with deficiencies and/or latent defects (non-conformities) such as laminate to core disbonding, laminate delamination, dry-laminates, physical damage, stress fractures and/or cracks, physical damage from allision/collision, groundings, shadowing/ghosting from prior repairs, weather event damage (lightning/storm damage), and moisture weepage should be isolated and forensically measured and labeled with adhesive measuring tape, numbers, and/or indicators.



12.4 Additional test should include a moisture analysis, using more than one type of moisture meter which display percent and relative readings.

12.5 For the hull bottom, the make and the Cuprous Oxide (Copper(I) oxide) content of the anti-fouling coatings would need to be obtained. Metallic components in antifouling coatings, graphite additives in some gel-coats, and structural Kevlar and Carbon Fiber layers will cause increased moisture level readings. For example: The Cuprous Oxide (Copper(I) oxide) content of Sea Hawk Cukoat™ 3445 Black anti-fouling coatings is 47.5%.<sup>9</sup> This information is readily available in the coating's safety data sheet.

<sup>9</sup> "Sea Hawk Premium Yacht Finishes", Cukote™ Safety Data Sheet, Version 5.0, Date of Issue: June 27, 2014, Revision Date: April 11, 2018.

- 12.6 A Shore-D or Barcol-Impressor hardness test should be conducted depending on the type of laminates and if applicable. Shore-D Hardness is primarily used in polyester resin and epoxy applications.
- 12.7 The thermographer/inspector should have the knowledge of the minimum acceptable tolerances for all three inspections (Moisture Analysis, Shore-D Hardness and/or Barcol-Impressor Hardness).

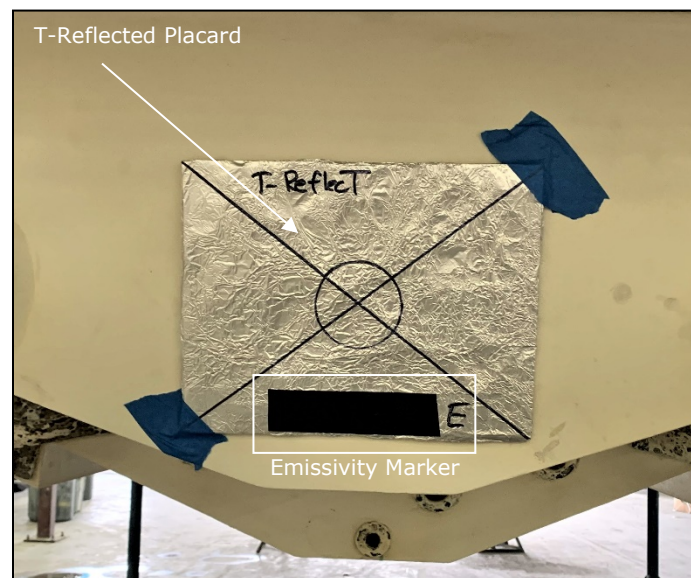
## 13.0 Thermal Imaging Inspection:

- 13.1 The parameters to set up the imager will need to be obtained prior to thermal imaging the vessel. This must include: the current atmospheric temperature, relative humidity, wind speed and direction, distance from the vessel, Emittance (Emissivity) of the vessel, and the T-Reflected/reflected apparent temperature.
- 13.2 Meteorological readings should be obtained. A Digital Temperature Humidity Meter should be used to obtain current atmospheric temperature and relative humidity. A hand held or mounted digital Anemometer should be used to obtain wind speed and direction. The use of cell phone applications should never be used to obtain meteorological readings.
- 13.3 To determine the T-Reflected, attach a piece of crumpled and smoothed-out aluminum foil to a piece of stiff cardboard or plastic board and/or a piece of sanded and profiled aluminum plate (placard). The placard is then attached to the vessel, the vessel and the placard are externally heated, and the temperature of the vessel and the placard are obtained. After three or four passes, the average temperature of the placard is the T-Reflected temperature. Reflected temperature cannot be lower than ambient temperature.<sup>10</sup> T-Reflected can be obtained by the use of the Thermal Imager or a Non-Contact Infrared Thermometer with Emissivity set to 1.0. The individual thermographer conducting the inspection would have learned this in their Level I training. Additionally, a complete outline of T-Reflected/Reflected Temperature can be researched in the *Standard for Measuring and Compensating for Reflected Temperatures using Infrared Imaging Radiometers, 2016 Edition, Infraspection Institute*©.

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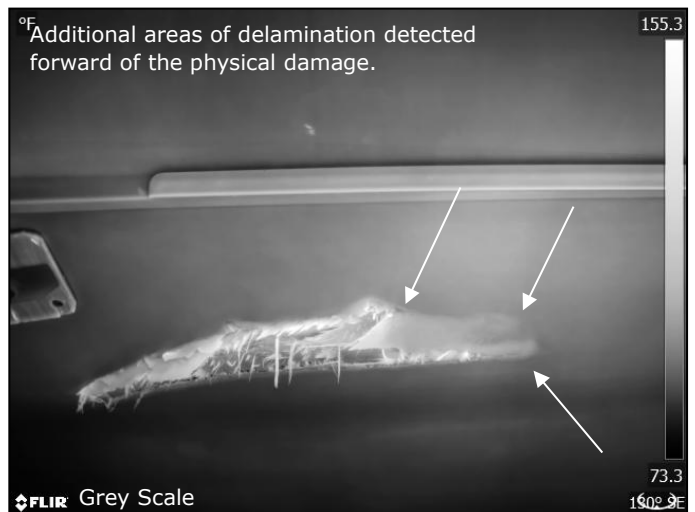
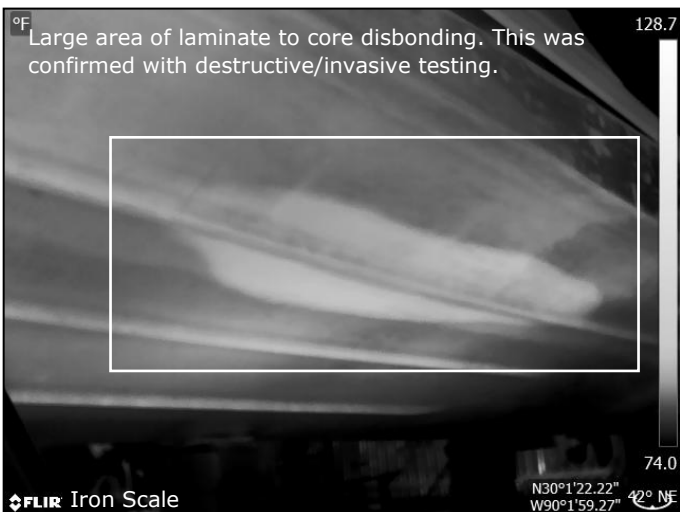
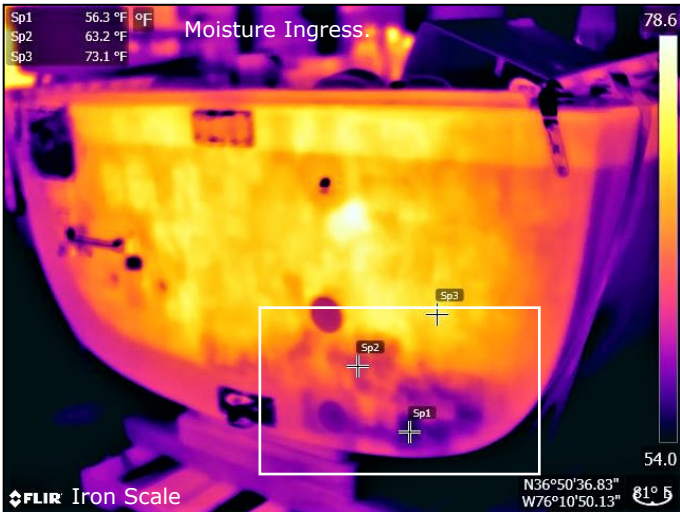
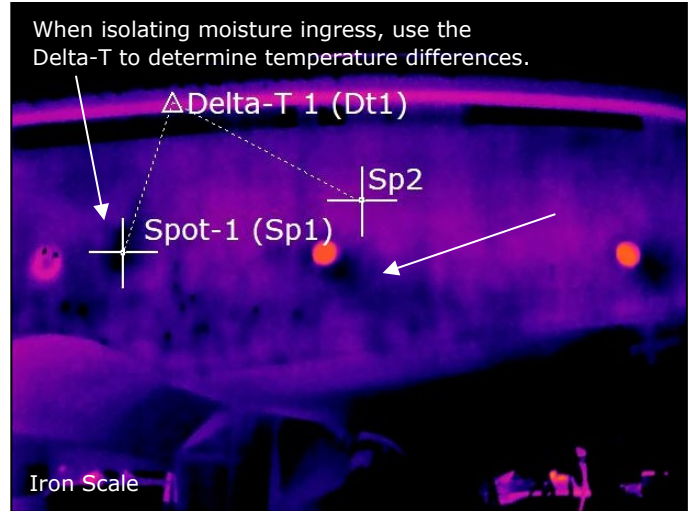
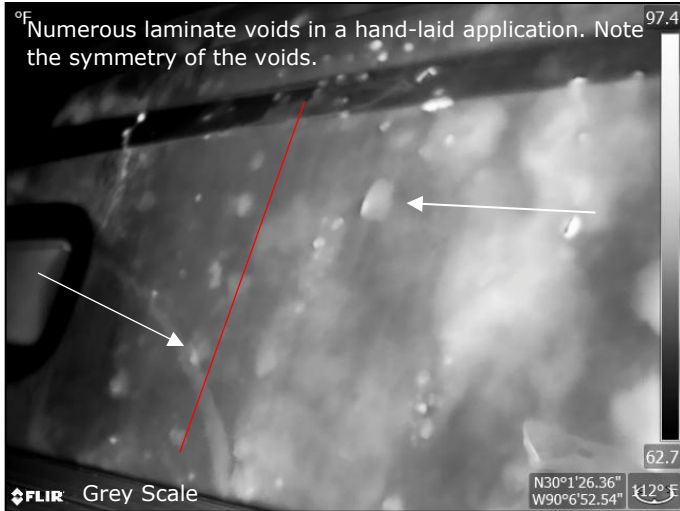
<sup>10</sup> *Infraspection Institute, Level II, Quantitative Theory and Application, 6, Reflection Errors and Corrections, Page 7, © Infraspection Institute.*

- 13.4 The vessel's Emissivity is obtained by attaching a piece of Scotch-type 33 or 88 black vinyl electrical tape to the area of the vessel that will be thermal imaged. This represents a Blackbody for determining the vessel's current Emissivity. The area is independently heated and the temperatures acquired. Once the temperature of the vessel is acquired, move the imager spot to the blackbody, and adjust the temperature of the imager until they are equal. This is the Emissivity for this inspection. Remember temperature affects Emissivity so you should determine and obtain the vessel's Emissivity for all thermal imaging inspections. This is a lengthy process. The individual thermographer conducting the inspection would have learned this in their Level I training.



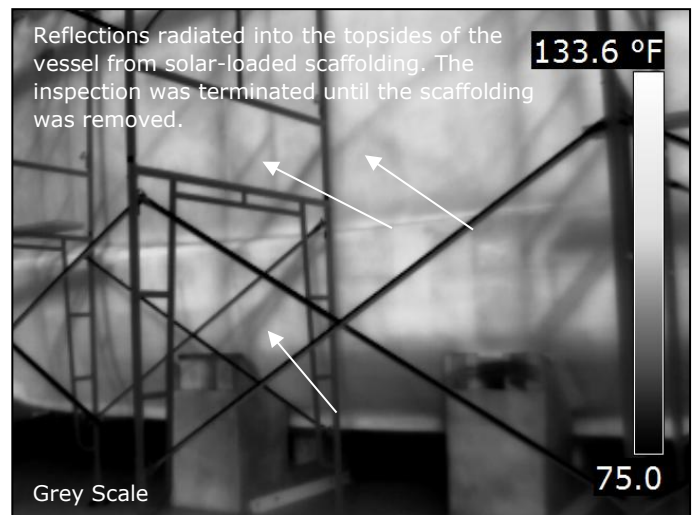
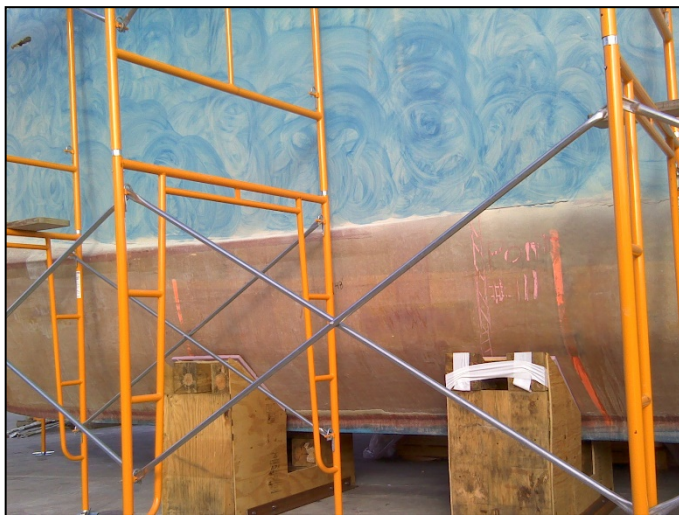
- 13.5 Both 13.3 and 13.4 are tutorial and should be within the skill set of the attending Thermographer outlined in 8.0: Thermographer Certification. Additionally, a complete outline of Emissivity/Emittance and Transmittance can be researched in the *Standard for Measuring and Compensating for Emittance using Infrared Imaging Radiometers and in Standard for Measuring and Compensating for Transmittance of an Attenuating Medium using Infrared Imaging Radiometers 2016 Editions*, *Infraspection Institute*©.
- 13.6 Program Apparent Temperature, Relative Humidity, T-Reflected, and Emissivity into the thermal imager.

- 13.7 The areas of the vessel to be inspected are then independently heated, and the thermal image of the area is captured with the thermal imager. The amount of heat needed to get the proper differential and break the thermal equilibrium depends on the vessel's location. Cool, less humid environments would need more heat, whereas warm and humid areas would need less heat.
- 13.8 LP/Propane Fired Heat Tools such as the Shrinkfast 998 and Ripack 3000-70 Propane Fired Heat Tool/Guns are accepted heating methods. They should only be used for the *external* inspections only. Proper control and care should also be taken to keep the heat of the tool moving so not to burn, scorch, and/or overheat the exterior coatings and/or underlying laminates.
- 13.9 The use of IR Heat lamps and AC Powered Heat Guns are a preferred method for warming internal areas of a vessel such as bilges and tanks. IR heat lamps transfer energy to a body with a lower temperature through electromagnetic radiation. They should be used to warm an area, but not used to heat the laminates.
- 13.10 Safety First! should always be observed when using an external heat source while conducting a thermal infrared inspection.
- 13.11 The first thermographic data to gather is in the Grey and Iron scales. When the area is warmed, the thermographer should be ready to take the image. Take more than one image and take them at different angles. During post processing and thermal tuning of the images, the scales can be changed to clearly isolate a Thermal Anomaly. The following images are examples of thermal anomalies using various color scales:



The above thermal images, captured by the creator of this guideline, were filmed using a FLIR T640 Digital 640 x 480 30 Hz Digital Thermal Infrared Camera with a FLIR f-13.1mm (45°) IR Wide Angle Lens.

13.12 A vessel with High Gloss topsides will cause reflections from adjacent objects or vessels. If using an imager that has FLIR MSX®, this can be used to isolate reflections caused by adjacent structures or vessels. Filming at non-perpendicular angles (45-degree) generally rectifies reflection issues. Filming at a perpendicular angle (also known as a right angle or 90° angle) to the object being captured generally will always cause reflections.



13.13 After isolation of the anomalies has been determined during the thermographic survey process, the areas should then be invasively and/or destructive tested, core samples and/or coupons of these areas should be obtained, and all coupons should then be sent to a composite lab for a complete analysis. The lab should specialize in laminate composition.

13.14 If the repairs are significant, a corrective action plan should be drawn and scheduled by a naval architect.

13.15 The repairs undertaken by a qualified laminate repair facility and/or qualified technician with the complete knowledge of vessel construction, laminate procedures, and vacuum infusion.

## 14.0 Reporting:

- 14.1 All thermal imaging inspections should be documented and report delivery times should be discussed prior to the inspection. Reports should consist of the following:
  - 14.1.1 Cover Page – Client Information, brief vessel description, a digital image of the vessel, date, and file number.
  - 14.1.2 Table of Contents
  - 14.1.3 Executive Summary – A short summary of the full report or document including a brief description of the vessel and summary of the visual and thermal imaging inspections.
  - 14.1.4 Vessel Particulars and Descriptions – This should include the vessel’s name, hull identification (HIN) or builder’s identification number, IMO Number, vessel registration or documentation and its type, classification society and type, vessel description to include hull type (displacement, semi-displacement, special service vessel, dimensions, displacement, tonnage, topsides and hull bottom coatings, builder and designer information, construction materials and/or the laminate schedule.

Example of an interpreted laminate schedule: The topsides are sandwich-type construction with ISO-NPG gel-coat, hand-laid fiberglass which is then vacuum infused. The first four layers use E-Glass Epoxy and end with Isophthalic (Polyester) Resins, Biaxial 450/150 +/- 45 Fiberglass Mat, Chop Strand Matt (CSM), and Polyvinyl Chloride (PVC) crossed-linked rigid closed cell (Airex®/Divinycell HP Type) Foam Core. (This is a manufactured description)

- 14.1.5 Introduction – Client information, vessel location, date of inspection, and type of inspection to be conducted.

For example; The below undersigned Thermographer was formally retained and did, at the request of name of individual requesting from vessel or company name, attend the vessel, vessel name, while hauled out of the water (dry-docked), blocked, and under cover at name, address, pad number, and country of facility on date of inspection, for the purpose of a general inspection to document moisture ingress, laminate to core disbonding, laminate delamination, and/or imperfections to the vessel's port and starboard topsides and hull bottom.

- 14.1.6 How to Interpret Findings – Thermographer should give a baseline description of what and how to understand the report or document.

- 14.1.7 Basic Vessel Descriptions and/or Terminology – As illustrated in Section IV of this document.

- 14.1.8 Visual Inspection and Evaluation of the vessel to note any deficiencies and/or damages.

- 14.1.9 Methods Used – Include measurements on how the vessel will be laid out/sectioned for the inspected. Digital pictures or Construction drawings help with these descriptions.

- 14.1.10 Conditions and Equipment – Detailed description of the vessel's infrared settings (Emissivity and T-Reflected), imaging times, and weather conditions. Also include a complete inventory of equipment used to include the thermal imager make, model, serial number, calibration date, and type and size of lens.

- 14.1.11 Thermal Images and Inspections Notes and Findings – This should include full descriptions of the following: all anomalies detected, if needed a Delta-T, if used spot temperatures, and the color palate used for the image. If using colored markers (arrows, boxes, lines) a description of what each color code would represent. For example: yellow marker – laminate disbonding, white marker – moisture ingress.

- 14.1.12      Comments and Conclusions – Basic findings and any recommendations for repair. A separate paragraph should include any standards, codes, and regulations that were applied to the inspection.
- 14.1.13      Disclaimer and/or Disclosure – Generally any statement intended to specify or delimit the scope of rights and obligations that may be exercised and enforced by parties in a legally recognized relationship. In contrast to other terms for legally operative language, the term *disclaimer* usually implies situations that involve some level of uncertainty, waiver, or risk.<sup>11</sup>
- 14.1.14      Curriculum Vitae or Resume – A document created by the thermographer/inspector/surveyor outlining their experience, certifications, and if requested, references.

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<sup>11</sup> [Wikipeda.org/Disclaimer](https://en.wikipedia.org/wiki/Disclaimer).