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| HQ108\_1 | Welcome to the Composite Overwrapped Pressure Vessels Overview course |
| HQ108\_2 | This course is designed to provide you with an overview of Composite Overwrapped Pressure Vessels, or COPV. |
| HQ108\_3 | At the completion of this course, you will be able to: demonstrate basic knowledge of Composite Overwrapped Pressure Vessels or COPV; describe the composite structure of a COPV; recognize how COPVs differ from metallic pressure vessels; identify safety hazards inherent to a COPV; describe types of COPV damage and failure modes; and classify and describe Damage Control Planning. |
| HQ108\_4 | This course is intended for: purchasing and procurement agents; maintenance and operations personnel; program and project managers; engineers; safety and quality assurance inspectors; vehicle integration support; component and system users; and anyone in the NASA community working on or around composite pressure vessel technology |
| HQ108\_7 | A composite overwrapped pressure vessel, or COPV is an enabling technology that allows us to do more work with less weight. They can provide the same performance requirements for fluid storage as a metallic pressure vessel. Lighter launch systems and sub-systems allow for more weight to be launched into orbit and planetary exploration. Smaller vehicles make the ambitious robotic missions to other cosmic planets possible. |
| HQ108\_9 | COPVs may be used as ground-based or flight pressure vessels. COPVs are used for high pressure fluid storage like: gas, for instance Helium, Hydrogen, Oxygen, Xenon, etc. with pressures up to 12,000 psi; or liquid, such as propellants (fuels and oxidizer), ambient and cryogenic or hypergolic, with pressures generally less than 1000 psi. The schematic shown illustrates a typical gaseous installation utilizing gaseous Helium. COPVs exposed surfaces should be evaluated for material compatibility. |
| HQ108\_10 | A COPV is a pressure vessel consisting of a liner overwrapped with fiber, designed to hold and dispense liquid or gas under pressure. The reinforcement fiber provides most or all of the tank's strength. The weight of COPVs are half as heavy as metallic designed pressure vessels operating at the same service pressure, but this may be offset by the increased costs of manufacturing and certification. COPVs are much lighter and stronger than the metal vessels they replace, in other words COPVs are roughly about half as heavy and twice as strong. It is a complex structure containing various materials used to construct a component. The liner is a hermetic seal that may or may not carry loads. The reinforcement fiber is most often constructed with carbon and sometimes with an outer layer of fiberglass. The reinforcement fibers carry partial or full load at service pressure. The resin system ensures proper fiber placement, facilitates load sharing, and provides some amount of surface protection. |
| HQ108\_11 | The COPV is designed using three different materials used to create the composite structure. The liner provides a barrier between the fluid and the composite, preventing leaks and loss of media from the structure. The most commonly used filaments in COPV construction are reinforced fibers made from carbon, and sometimes other fiber types. The matrix/resin system is generally made of two-part epoxy, polyimides, or other strong adhesives. This resin system is part of the reinforcement fiber (wet-wound or prepreg) during manufacturing. The resin helps the reinforcement fiber share load and offers a minor level of protection. |
| HQ108\_12 | Mounting methods and locations vary from hoop or boss. These methods can occur on interior (wet/dry) or exterior to the flight vehicle. These mounting locations drive cleanliness and handling requirements. Expansion of COPVs should be considered when determining and designing mounting method and location as COPVs exhibit up to 10% of the expansion of comparable sized metallic pressure vessels. |
| HQ108\_14 | Correct answer: C |
| HQ108\_16 | COPV liners and overwraps are highly susceptible to impact damage, specified as fracture critical. Fracture critical is defined as a classification that assumes that cracks in the hardware could lead to a catastrophic failure, an event that results in loss of life, serious personal injury, loss of the manned flight system, or loss of mission. Impacts cause large variances in reductions in burst strength. There are significant influence parameters which include: impact energy, how hard it was impacted; impact geometry, all geometries can break fibers; COPV geometry/design and ply lay-up; and COPV pressure state and fluid type (liquid or gas). This susceptibility reiterates the need for a damage control plan and need to report mechanical damage. Because COPVs are so susceptible to damage, damage control plans provide requirements that must be followed to protect them throughout the manufacturing and lifetime of a COPV, therefore damage control plans need to be reviewed and understood |
| HQ108\_18 | Here we see examples of the effects of impact damage to the overwrap of a COPV. The broken fibers are highlighted in red on the negative image of the impact indications. Any witnessed or perceived impact damage especially with broken fibers must immediately be reported. Please take a moment to further review these two examples |
| HQ108\_19 | Let's take a look at additional data that would be examined during impact damage testing. Multiple tests performed at same impact conditions resulted in large variations in the reduction of burst strength after the impact event. The following greatly affect the amount of damage and reductions in burst strength: amount of impact energy - low energy, high energy, and hyper energy; location of the impact on COPV surface; geometry of the impactor; and pressure state of the COPV. Data is limited to the types of testing and the test articles tested. COPVs vary widely in liner material and thickness, wrap pattern, and other aspects. Mechanical impact damage greatly affects the ability of the COPV to contain high pressure. It is safety and mission imperative that mechanical damage be reported immediately |
| HQ108\_21 | Catastrophic rupture may occur over time or during refilling of the vessel. Visual inspections by trained inspectors must be performed prior to pressurization, after any mechanical impacts are reported and prior to any re-flight or use. COPVs that were impacted and held at service pressure determined that some increased level of damage growth appeared superficial, and more test data needs to be obtained with respect to re-flight or re-pressurization of COPVs. Multiyear testing is needed. Testing that started in November 1997 is to provide answers and solve some of the problems. Testing involved multiple COPVs impacted at roughly a 20% reduction in burst strength then continuously held at service pressure |
| HQ108\_22 | Material compatibility test summary determined the COPV surface is exposed to aerospace fluids like Hydrazine fuels (N2H4, MMH, UDMH), Oxidizer (N2O4), and Cryogens (LOX, LN2). COPVs immersed in liquid oxygen, also known as LOX, demonstrate shock sensitivity when impacted. Superficial or insignificant effects of exposure on sample coupons (including oxidizer) considered weight, hardness, and flex strength (known as the three-point bend test). Propellants had NO measurable effect on burst strength of the COPVs tested. Verification should be made with ADP (Acceptance Data Pack), Vendor, or Program for approved fluids prior to any cleaning. Special consideration is needed for exposure of resin system to oxygen (Liquid or Gaseous). |
| HQ108\_23 | Results of coupon testing noted shock sensitivity in LOX exposure, propellant visual indications after surface exposure, including minor surface dulling with fuels and yellow oxidizer/matrix reaction product; and no significant strength loss or modulus change, i.e. three-point bending. The propellant exposure was to the exterior surface of the COPV. Look closely at the examples here. You see the sample coupon pointing out the highlighted area that was tested. As you can see in the image of the vessel, the COPV did not fail in the yellow area of fluid exposure. |
| HQ108\_24 | Ensuring that COPVs are well understood including the use environment and are used, installed, and integrated free from damage is paramount and has direct consequences with respect to safety and mission assurance. This dramatic COPV compatibility failure video is an example of the burst and cascading consequences of the rupture of a COPV during service. It demonstrates the amount of stored energy COPVs are capable of containing and the resulting consequence if damage occurs. While it's often hard to discern where the failure of a COPV occurred, you can't see the area of fluid exposure in this example, although it is assumed where the failure started. Select to view. |
| HQ108\_25 | Understanding why and how COPV damage is relevant to mission success is critical. Damage to COPVs will be inspected by trained inspectors. COPVs as a tension-dominated structure are susceptible to impact damage because carbon fibers are weak in shear. Understanding the residual, or left over, strength after damage is vital to safety and mission assurance. Impact damage is difficult to discern by an untrained inspector and even sometimes by trained inspectors. Consequently, training is necessary in addition to this course to qualify as a COPV inspector. The accepted training at a minimum is the WSTF COPV Damage Detection Course. Any and all impact damage shall be reviewed by qualified/certified inspectors. Residual strength cannot be quantified by any NDE method and all mechanical impacts shall be reported. The material review board will determine the final disposition of the hardware. |
| HQ108\_26 | External damage visual indications DO NOT quantify the potential damage extent. Subsurface broken fibers and delamination may exist that are hidden from view. Specialized non-destructive analysis helps to determine actual damage state. Composite damage can result in catastrophic failure. COPV strength and life may be less than the original design at service pressure. Release of large amounts of stored energy occurs, along with associated high velocity fragmentation. No NDE method exists to quantify residual strength and therefore all damage needs material review consideration for final disposition. The material review board will provide disposition of the hardware. Report all damage as non-conformance and reporting is necessary |
| HQ108\_27 | Correct answer: D |
| HQ108\_29 | Here is a list of safety hazards and PPE to consider when dealing with COPVs: Large amounts of stored energy caused by pressure and sometimes chemical explosions require s area clears, barricades and fortification; dust inhalation necessitates use of respiratory protection; skin irritants require protective clothing; electrically conductive directs the isolation of electronics; and carcinogenic combustion plume requires a self-contained breathing apparatus. Burn products from the resins used in composites are known to be carcinogenic. Skin and lungs require personnel protective equipment (PPE). The following section will now focus on stored energy and its impact on safety |
| HQ108\_30 | When looking at examples of stored energy we see great differences in the effect of damage based on the COPV storage fluid. The amount of risk due to failure is mostly based on the COPV storage or handling fluid, for instance hydraulic (liquid) or pneumatic (gas). Resulting failure and hazards from impact are influenced by different conditions. The risk is greater in high pressure gas storage. Most Aerospace use is high pressure gas. Hydrostatic storage also influences the failure and hazards due to impact. Even storage of propellants can be an influence. Due to these differences and potential cascading events, this enforces the need for visual inspections by a qualified inspector be performed prior to any re-pressurization and/or re-flight. |
| HQ108\_31 | COPVs contain large amounts of stored energy, upwards of 15 pounds T-N-T equivalence. Rupture can generate large over-pressure waves up to 12 psi overpressure, which is well above Occupation Safety and Health Administration (OSHA) acceptable limits for personnel exposure. Additionally, high velocity fragmentation may approach Mach 2: ~2,200 feet per second. Over-pressurization and fragmentation may cause risk to personnel, facility including flight hardware, and the environment. Standards and modeling exist to estimate over-pressurization and fragmentation. |
| HQ108\_32 | Here we see the differences in fragmentation caused by a hydrostatic burst versus a pneumatic burst. Select each to view the differences. |
| HQ108\_33 | Let's take a look at the types of failures that can occur when dealing with COPVs. Burst before leak, or BBL, is a COPV situation in which the vessel fails catastrophically under pressure before it leaks. Leak before burst (LBB) is a COPV situation in which the vessel leaks under pressure before it bursts. A damage control plan is required for ALL COPVs used in flight and proto-flight systems and launch vehicles. It is a living design document that must be read/reviewed and understood. |
| HQ108\_34 | A Damage control plan (DCP) is an approved process addressing COPV damage prevention and protection from potential mechanical damage for the life of the component. It is required by AIAA S-081, AFSPCMAN 91-710, and KNPR 8715.3. It includes, at a minimum a credible threat analysis, damage mitigation (protection, prevention, surveillance, etc.) and all detailed visual inspection points for the service life of the COPV. It identifies protective measures required to prevent damage. A DCP is required prior to procurement and shall be maintained for the life of the COPV including any re-use |
| HQ108\_35 | Correct answer: B |
| HQ108\_36 | Correct answer: D |
| HQ108\_38 | Training is essential when dealing with COPVs. Trained COPV visual inspectors shall be utilized on projects per existing requirements. Qualified inspectors per a written certification practice shall be subject to approval from customer and/or AHJ, Authority Having Jurisdiction, and require additional training such as On-the-Job Training (OJT) and applicable damage detection training. They are recognized as competent authorities per the AHJ. The AHJ may be range safety, site quality organization(s), program leads and/or Safety and Mission Assurance, naming just a few. |
| HQ108\_39 | Visual detection threshold (VDT) is an impact energy level that creates an indication barely detectable by trained inspector using unaided visual inspection technique. Visual inspection (VT) is an inspection technique that uses qualified visual inspectors to evaluate COPV shell and liner for evidence of damage or non-conformance |
| HQ108\_40 | Level one damage contains visible damage to the surface of a composite structure that does not affect the fiber tows or reduce the residual strength. This level of damage is often limited to the resin system. Level two damage contains visible damage to the surface of a composite structure that results in broken or cracked tows, discoloration, gross ply disorientation, or hardware with non-traceable identification. Level two damage will result in a discrepant condition or non-conformity resulting in material review (MR). Any mechanical impact to the surface of a COPV suspected or observed is considered a non-conformance. If any hardware lacks traceability (i.e. Part or Serial Number for example) this is a non-conformance. WSTF-RD-1193-001-12 provides supplementary guidance when dealing with damage and COPVs. Select to view this additional information. |
| HQ108\_41 | Surface indications should be of concern. They include: impact or mechanical damage, scratches/cuts/abrasions, manufacturing indications, and/or discoloration. They should be reported as level one if there is no observed fiber damage or level two if there is fiber damage resulting in Material Review Board or MRB. Regardless of level, ALL observed or suspected damage shall be reported. |
| HQ108\_43 | Operations for flight shall occur in clean rooms and any open ports must have clean room bags. Internal cleanliness prevents leakage from liner or weld corrosion; maintains cleanliness for interfacing system; and is required for control of ignition hazards in fight pressure systems, including oxygen and propellant systems. External cleanliness ensures bond interface between structural elements, i.e., liner, film adhesive, overwrap; complies with space system cleanliness requirements; and protects sensitive aerospace equipment, i.e. optics, on-orbit tests, etc |
| HQ108\_44 | In summary, COPVs are susceptible to impact damage as they are fracture critical hardware. All mechanical impact must be reported, "if you see something, say something to someone". A Damage Control Plan is required for all COPVs. The plan includes visual inspection requirements and timing, analysis of credible threats for the lifetime of the COPV, and protective measures to prevent damage. Protective measures exist to prevent impact damage and must be followed. Special care must be followed during pressurized testing and pressurized work-around. Any impact or damage shall be reported as a non-conformance by establish reporting procedures. |
| HQ108\_46 | Take a moment to review additional resources that may be of interest on COPV safe and reliable use.  Additional Information https://standards.globalspec.com/std/10386462/AIAA%20S-081 |
| HQ108\_47 | For additional training please refer to the following courses. |
| HQ108\_48 | You should now be able to: demonstrate basic knowledge of Composite Overwrapped Pressure Vessels or COPV; describe the composite structure of a COPV; recognize how COPVs differ from metallic pressure vessels; identify safety hazards inherent to a COPV; describe types of COPV damage and failure modes; and classify and describe Damage Control Planning |
| HQ108\_49 | Once you've completed this course, you'll be notified in your SATERN Alerts that you have a survey waiting. Please consider completing the survey to let us know your opinions about this course. If you have any content related questions or issues with this course, please contact the NSC Help Desk. The Help Desk will pass your inquiry on to the team for a response. We'll make every effort to get back to you in a timely manner. |
| HQ108\_50 | Congratulations, you've completed the course. To register completion in SATERN, select 'complete' and proceed to take the test. |