APPENDIX A
BASIC REQUIREMENTS FOR FULLY WRAPPED CARBON-FIBER REINFORCED ALUMINUM LINED CYLINDERS(DOT-CFFC)

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CFFC-1 **SCOPE:** These basic requirements (DOT-CFFC) cover design, manufacture, and performance requirements for cylinders made of a seamless aluminum liner over wrapped with structural layers of filament wound carbon fiber and epoxy composite material.

CFFC-2 **TYPE, SIZE AND SERVICE PRESSURE**:

The CFFC cylinder is a seamless aluminum alloy liner wound with carbon fiber and glass fiber reinforced plastic full composite layers and subjected to an autofrettage pressure. Carbon filament wound and epoxy layers are the predominant pressure load bearing elements. An outer glass filament wound and epoxy layer provides damage protection. A galvanic corrosion protection layer is required for the aluminum liner. An inner glass filament wound and epoxy layer is allowed for galvanic corrosion protection. Together, the inner and outer glass filament layers must carry less than 15 percent of the total pressure load at the minimum required burst pressure.

The winding pattern may be a combination of helical (including near longitudinal) and hoop. Layers made up of more than one type of fibers are not authorized.

The maximum permitted water capacity may not exceed 90.7 liters (200 pounds).

The marked service pressure may not exceed 34,474 kPa (5000 psi) at a reference temperature of 21.1 °C (70^0F). The test pressure is 5/3 times the design service pressure. The cylinder must have a minimum safety factor (burst/service pressure ratio) of 3.4.

CFFC-3 **SERVICE LIFE**: Cylinder service life is 15 years from the date of manufacture. The Associate Administrator for Hazardous Materials Safety (AAHMS) may approve an extension of cylinder service life up to a total service life of 30 years. A service life extension approval is made by modification to the exemption authorizing cylinder construction. Approvals of service life extension will be addressed under the following procedures:

1. The cylinder manufacturer must submit a Service Life Extension Plan that includes: a cylinder life cycle analysis; an in-service inspection and testing program to monitor and validate the cylinder life cycle analysis; and a proposal for the periodic reporting of data to the AAHMS. This Plan must be submitted as a part of the original exemption application.

2. The in-service inspection and testing program must begin within one year of the date the exemption is granted.

3. The manufacturer must submit a final report based on data gathered during the in-service inspection and testing program, on cylinders with service lives up to 12 years. This report must be submitted to the AAHMS no more than 13 years after the date the original exemption is granted.

4. The AAHMS will make a decision to approve or reject a service life extension based on the review of the final report. The manufacturer will be notified of the decision within 180 days after the AAHMS receives the final report.

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CFFC-4 **INSPECTION BY WHOM AND WHERE**: Inspection and verification must be performed by an independent inspection agency approved in writing by the Associate Administrator for Hazardous Materials Safety (AAHMS) in accordance with the Code of Federal Regulations, 49 CFR 173.300a. Chemical analysis must be approved for each procurement batch in accordance with 49 CFR Subchapter C Section 173.300b. Applicable fiber strength properties must be verified in accordance with CFFC-6(b) and approved by the independent inspector for each procurement batch.

CFFC-5 **DUTIES OF INSPECTOR:** The independent inspector shall perform the following verification procedures to ensure that each cylinder manufactured conforms with the design and performance parameters set forth for that cylinder.

(a) Obtain and retain copies of design calculations, drawings, material certifications, and approval documents as applicable to each design type.

**** (b) Determine that all materials and components comply with the provisions of this standard. Except when stated otherwise, a material identified by the materials or component manufacturer's certified statement as to meeting the procurement specification(s) is acceptable.

(c) Verify the chemical composition of each heat of liner material either by analysis or by obtaining the materials manufacturer's certified analysis. A certification by the cylinder manufacturer indicating compliance with the above requirement is acceptable provided (I) the certification is verified by a check analysis on one sample liner taken out of each lot of 200 or less liners successively produced, and (ii) the

traceability of that material to its manufacturer is established.

(d) Verify all fiber materials for conformance with the cylinder manufacturer's material specification(s), and for uniform and consistent quality.

(e) Verify all resin materials, and other chemicals for conformance with the cylinder manufacturer's material specification(s), and for uniform and consistent quality.

(f) Verify liners with all requirements including dimensions, inner surface smoothness, heat treatment, threads, and corrosion protection.

(g) Verify filament winding and curing procedures.

(h) Verify cylinders for conformance with all requirements including marking, dimensions, inner surface finish, heat treatment, threads, and galvanic corrosion protection in accordance with manufacturer's specifications and drawings.

**** (i) Witness all tests and pressurization on completed cylinders, obtain copies of all test results and certifications; report volumetric capacity, elastic expansion, and total expansion at autofrettage stage and subsequent test pressure, liner weight, and the completed cylinder weight.

(j) Complete inspector's reports as prescribed in CFFC-15 of this standard. Provide a copy of the reports to the cylinder manufacturer and upon request to the purchaser.

(k) Prior to the initial shipment of any specific design or design change, verify that design qualification tests prescribed in CFFC-10 of this standard have been performed with acceptable results.

CFFC-6 **AUTHORIZED MATERIAL AND IDENTIFICATION OF MATERIAL**.

(a) **Liner**: The liner must be a seamless cylinder made of aluminum alloy 6061 of T-6 temper.

(i) The liner may be produced by cold or hot backward extrusion; cold drawing; or from an extruded tube with swaged or spun ends.

(ii) The material composition of the alloy used

must be within the limits prescribed herein:

ELEMENT	ALLOY 6061	
	MIN %	MAX %
Silicon	0.40	0.80
Iron		0.70
Copper	0.15	0.40
Manganese		0.15
Magnesium	0.80	1.20
Chromium	0.04	0.35
Zinc		0.25
Titanium		0.15
Lead		0.005
Bismuth		0.005
Others Each		0.05
Others Total		0.15
Aluminum	Remainder	

(iii) The liner interior surface shall be smooth. Any fold in the neck region due to the forming or spinning process must not be sharp or deep or detrimental to the integrity of the cylinder. Inner surface defects may be removed by machining or other method, provided the metal loss is minimal and the minimum required wall thickness is maintained.

(iv) Liner ends must be concave to pressure.

(v) Prior to any test, all cylinders must be subjected to a solution heat treatment and aging heat treatment appropriate for aluminum alloy 6061. The process must produce liners of uniform temper and properties.

(vi) The limits for the mechanical properties of alloy 6061 T6 temper prior to filament winding shall be as follows:

	6061-T6
Yield Strength (Min)	241,316 kPa

		(35,000 psi)
	Tensile Strength (Min)	262,001 kPa
		(38,000 psi)
****	Elongation 5.1 cm(2"gage)(Min)	14%
	Elongation (24t X 6t)	10%

(vii) The outer surface of each liner must be protected from any galvanic corrosion that may occur due to dissimilar materials (aluminum and carbon fibers) in contact. A suitable polymer coating or glass-fiber/epoxy composite layer may be used for this purpose.

(viii) Physical tests. To determine yield strength, tensile strength and elongation of the aluminum liner material. Applies to aluminum liner only.

(A) Required on 2 specimens cut from one liner taken at random out of each lot of 200 liners or less. A "lot" means a group of cylindrical liners successively produced having the same: size and configuration, specified material of construction, process of manufacture and heat treatment process conditions.

(B) Specimens must be: Gauge length of 5.1 cm (2 inches) with width not over 3.8 cm (1-1/2 inches); or gauge length of 4 times the specimen diameter (4D bar); a specimen with gauge length at least 24 times the thickness with the width not over 6 times the thickness is also authorized when the liner wall is not over 0.48 cm (3/16 inch) thick. The specimen, exclusive of grip ends, must not be flattened. Grip ends may be flattened to within 2.5 cm (one inch) of each end of the reduced section. When the size of the liner does not permit securing straight specimens, the specimens may be taken in any location or direction and may be straightened or flattened cold and by pressure only, not by blows. When such specimens are used, the inspector's report must show that the specimens were so taken and prepared. Heating of specimens for any purpose is not authorized.

(C) The yield strength in tension shall be the stress corresponding to a permanent

strain of 0.2 percent of the gauge length.

(1) The yield strength shall be determined by the "offset" method as prescribed by ASTM Standard E8-78.

(2) For the purpose of strain measurement, the initial strain shall be set while the specimen is under a stress of 41,369 kPa (6,000 psi), the strain indicator reading being set at the calculated corresponding strain.

(3) Cross-head speed of the testing machine shall not exceed 0.32 cm (1/8 inch) per minute during yield strength determination.

(b) **Filament materials**:

(i) Carbon fibers: Must be polyacrylonitrile (PAN) based carbon fiber tows having mechanical properties meeting a specified procurement document. The mechanical properties of the fibers must be established for each procurement batch by testing in accordance with ASTM D-4018-93 and have a minimum strand strength specified in the cylinder manufacturer's material specification document. The tensile strength may not exceed 5,171,068 kPa (750,000 psi), the modulus of elasticity may not exceed 290 million kPa (42 million psi), and the strain to failure may not be less than 1 percent.

**** (ii) Glass fibers: Only type S and type E glass fibers are authorized. Filaments must be tested in accordance with ASTM D-2343-95 and have a minimum strand strength as follows:

Type S Glass ----2,757,903 kPa (400,000 psi)

Type E-Glass ----1,378,951 kPa (200,000 psi)

(iii) Fiber strength: In lieu of testing for fiber strength by the cylinder manufacturer, a certificate by the fiber manufacturer is acceptable provided that the cylinder manufacturer's material specification document specifies strength and quality requirements and that the supplied material meets those requirements.

**** (c) **Resin matrix materials**: Resin matrix systems must be epoxy or modified epoxy type having a pot life compatible with the filament winding process used. The resin matrix system selected must have sufficient ductility so that cracking of the resin matrix system does not occur during the manufacturing of the cylinder or during normal operation for the useful life of the cylinder. The cylinder manufacturer shall verify that each batch of resin/hardener mix is of satisfactory quality and properties within specified tolerances, and shall maintain such records as needed to be able to identify the cylinders manufactured from each batch of materials.

(d) **Overwrapped**: The composite overwrap shall be formed by layers of continuous fibers in a matrix. Helical or near longitudinal windings must cover the entire surface of the liner. When circumferential layers are interspersed for strengthening the side wall, physical discontinuity between the layers must be minimized.

(i) Co-mingled fibers are not authorized. Each layer may contain one type of fibers only.

(ii) Both wet winding and pre-impregnated filament winding is authorized.

(iii) For each design type cylinder the following parameters shall be defined and recorded:

(A) Number of strands used
(B) Winding tension
(C) Winding pattern (angles, pitch and order of layers)
(D) Winding speed
(E) Curing cycle
(F) Resin content
(G) Quality assurance procedures

CFFC-7 **DESIGN CRITERIA**:

**** (a) General: The design and stress analysis of a CFFC cylinder is complex because of the varying load bearing layers, the varying orientation and thickness of composite layers, and the necessity that the aluminum liner is subjected to above yield strains at the time of autofrettage pressure cycle.

A reliable model of the cylinder must be used in order

to calculate the maximum stress at any point in the liner and fibers; and load distribution between liner and fibers at zero pressure, service pressure, test pressure, and burst pressure. For these purposes, as a minimum, the model used to analyze the cylinder body must be based on thin shell theory, must account for non-linear material behavior and nonlinear geometric changes, and it must account for both circumferential and longitudinal pressure stresses. Only the cylinder body must be analyzed. Note: maximum stresses in the cylinder ends must always be less than the maximum stresses in the cylinder body to pass burst tests.

This analysis will require that finite element techniques be used to satisfactorily analyze the stresses in the fibers. The model and analysis procedure must be specifically described and documented. The maximum calculated tensile stress in any fibers (carbon or glass) may not exceed 30 percent of the fiber stress corresponding to the minimum required burst pressure.

(b) Stress Distribution requirements:

(i) The maximum calculated tensile stress at any point in the liner at the service pressure may not exceed 60 percent of the yield strength of the liner as measured according to section 6(a) of this document. The compressive stress in the sidewall of the liner at zero pressure must be at least 60 percent but no more than 95 percent of the minimum yield strength of the liner material as determined per CFFC 6(a)(viii).

(ii) Glass fibers used for galvanic corrosion protection of the liner and for damage protection of the cylinder must be such that its net load sharing capability may not exceed 15 percent of the total pressure load in the cylinder at minimum required burst pressure.

(iii) The maximum fiber stress at service pressure of the carbon fibers or glass fibers may not exceed 30 percent of the fiber stress corresponding to the minimum required burst pressure.

(iv) The burst failure mode shall initiate in the cylinder side wall.

CFFC-8 **OPENINGS, VALVES, AND PRESSURE RELIEF DEVICES**:

(a) **Openings**:

(i) Openings are permitted on heads only. The centerline of the openings must coincide with the centerline of the cylinder.

(ii) Threads must be clean cut, even, without checks, and must be designed in compliance with the requirements of the Federal Standard FED-STD-H28, Appendix A5.

(iii) Tapered threads are not permitted.

(iv) Straight threads having at least 6 threads must have a calculated factor of safety in shear of at least 10 at the test pressure for the cylinder. The threads must extend completely through the neck.

(b) **Valves, pressure relief devices, connections, and valve protection**:

Selection of valves and pressure relief devices must conform to the requirements in Compressed Gas Association (CGA) Pamphlet S-1.1, 1994 edition and must be in compliance with the requirements in 49 CFR 173.34(d) and 173.301(g) except that the adequacy of the pressure relief device is determined by bonfire test as prescribed in CFFC-10. The rated bursting pressure of a rupture disk at ambient temperature must be not less than 83 percent nor more than 100 percent of the cylinder test pressure.

CFFC-9 **DESIGN TYPE AND AUTHORIZATION:**

(a) For each original cylinder design type, an application for a Department of Transportation Exemption shall be submitted in accordance with 49 CFR 107.105. Application may be made for multiple design types in one exemption application, provided there are variations in size and pressure only. An exemption must be granted in order for the cylinder to be authorized for the transportation of hazardous materials.

(b) For each original cylinder design type, detailed drawings showing dimensions, including tolerances, bill of materials, a description of manufacturing and quality assurance procedures, and results of design

qualification tests must be submitted to the Office of Exemptions and Approvals (OHMEA) before first shipment.

(c) A design type means cylinders of the same configuration (diameter, water capacity, service pressure, winding pattern), material specifications, design analysis procedures, manufacturing process, and manufacturing facility.

(d) A cylinder is not considered to be of a new design type, and no additional application or tests are required, if the deviation from the original design type is as follows:

(i) the change in diameter or service pressure is 10 percent or less, or the change in water capacity is 30 percent or less;

(ii) there are minor changes in the manufacturing process, quality assurance procedures, material properties, or winding pattern that have no significant effect on cylinder quality or performance.

(e) Cylinders representing design changes from the original design type (other than those in paragraph (d)) must be subjected to testing in accordance with CFFC-11. The applicant must make a request for modification to the exemption in order for the cylinders representing the design change to be listed as authorized cylinders. Detailed drawings and design qualification test results must be on file with the OHMEA before first shipment.

CFFC-10 **DESIGN QUALIFICATION TESTS AND ACCEPTABLE TEST RESULTS**:

**** Prior to initial shipment of any cylinder design type, qualification tests as prescribed herein shall have been performed with satisfactory results. For each design type qualification a sufficient number of cylinders shall be produced in a batch to permit all qualification tests to be carried out. Cylinders must be produced using the same materials, manufacturing equipment types, manufacturing processes and quality assurance procedures as used for production. The independent inspector must witness all design qualification tests. From the above batch of cylinders the independent inspector will select cylinders at random for each qualification test.

(a) **Resin System:** The resin system shall be tested on a

sample coupon representative of the composite over wrapped in accordance with ASTM D-2344-89 for water boil shear test. The minimum shear strength may not be less than 34,474 kPa (5000 psi).

* (b) **Burst Test**: The minimum required burst pressure is 3.4 times the marked service pressure marked on the cylinder. A minimum of three cylinders must be hydrostatically tested in accordance with the following:

(i) **Procedure:** Pressurize each cylinder at a uniform rate up to 3.4 times the marked service pressure marked on the cylinder, and hold at that pressure for a minimum of 60 seconds. The rate of pressurization may not exceed 1,379 kPa (200 psi) per second. Increase the pressure to failure and record the pressure at the onset of failure. Cylinders used in the ambient temperature cycling test may be used for the burst test.

(ii) **Acceptable test results**: In no case may the burst pressure of any cylinder be less than the required minimum burst pressure. The failure initiation must be in the cylindrical part of the cylinders.

(c) **Drop Test**: At a minimum, one empty cylinder, complete with valve but uncharged must be subjected to a drop test from a height of 3 meters (10 feet) onto a concrete surface in accordance with the following:

(i) **Procedure:**

Drop 1: The cylinder shall be dropped vertically onto the end.

Drop 2: The cylinder shall be dropped horizontally onto the sidewall.

Drop 3: The cylinder shall be dropped horizontally onto a 3.8 x 0.48 cm (1½ x 3/16 inch) piece of angle iron, with the included angle in the downward position. The cylinder shall land at right angles to and on the heel edge of the angle iron, impacting approximately in the center of the sidewall.

**** (ii) **Acceptable test results, if one cylinder tested:** The cylinder must be subjected to 1,000 pressure cycles from not greater than 10 percent

of service pressure and the service pressure at a rate not to exceed 10 cycles per minute. The minimum dwell time in the pressure range between 90 and 100 percent of the service pressure may not be less than 1.2 seconds. The test cylinder must withstand the cycling pressurization test without any evidence of visually observable leakage or damage growth during or after the pressure cycle test. After successfully passing the cycling test, the cylinder must be burst tested in accordance with the procedure described in CFFC-10(b)(i) of this standard. The residual burst strength of the cylinder must be at least 90 percent of the required minimum burst pressure (3.06 times service pressure). The cycling and burst pressure test data must be submitted to the DOT for the information data base.

**** (iii) **Acceptable test results, if two cylinders tested:** One cylinder must be subjected to 1,000 pressure cycles from not greater than 10 percent of service pressure and the service pressure at a rate not to exceed 10 cycles per minute. The minimum dwell time in the pressure range between 90 and 100 percent of the service pressure may not be less than 1.2 seconds. The test cylinder must withstand the cycling pressurization test without any evidence of visually observable leakage or damage growth during or after the pressure cycle test. After successfully passing the cycling test, the cylinder must be burst tested. The rate of pressurization may not exceed 1,379 kPa (200 psi) per second. Increase the pressure to failure and record the pressure at the onset of failure. The burst pressure must be recorded.

The other cylinder must be burst tested in accordance with with the procedure described in CFFC-10(b)(i) of this standard. The residual burst strength of the cylinder must be at least 90 percent of the required minimum burst pressure (3.06 times service pressure). The cycling and burst pressure test data for both cylinders must be submitted to the DOT for the information data base.

(d) **Ambient temperature cycling pressurization test**: At a minimum, two cylinders must be subjected to cycling pressurization tests in accordance with the following:

(i) **Procedure:** Pressurize the cylinder between a pressure not greater than 10 percent of service pressure and the service pressure at a rate not to exceed 10 cycles per minute. The minimum dwell time in the pressure range between 90 and 100 percent of the service pressure may not be less than 1.2 seconds. Each cylinder must be subjected to a minimum of 10,000 cycles. Following the cycling test to service pressure, each cylinder must be subjected to a minimum of 30 pressurization cycles by pressurizing between approximately zero and the minimum required test pressure. The dwell time between 90 and 100 percent of the maximum test pressure may not be less than 1.2 seconds.

**** (ii) **Acceptable test results**: Each test cylinder must withstand the cycling pressurization test without any evidence of visually observable damage, distortion or leakage. After successfully passing the cycling test, the cylinder must be burst tested in accordance with the procedure described in CFFC-10(b)(i) of this standard. The residual burst strength of the cylinder must be at least 90 percent of the required minimum burst pressure (3.06 times service pressure).

(e) **Environmental cycling tests**: Two cylinders must be cycle tested in accordance with the following:

(i) **Procedure:** The cycling rate may not exceed 10 cycles per minute. The dwell time between 90 and 100 percent of the maximum cycling pressure may not be less than 1.2 seconds:

Step 1. Condition for 48 hours at zero pressure, 60°C (140^0 F), and 95 percent humidity

Step 2. Pressurize from zero to service pressure for 5000 cycles at 60°C (140^0F) or higher, and 95 percent or greater humidity.

*** Step 3. Stabilize at zero pressure and at ambient conditions. Place in an environmental chamber at minus 51.6°C (minus 60^0F) or lower and then pressurize from zero to service pressure. The cylinder shall be subjected to a minimum of 5000 pressurization cycles.

Step 4. Stabilize at zero pressure and at ambient conditions, and then pressurize from zero to test pressure at ambient temperature. The cylinder shall be subjected to a minimum of 30 pressurization cycles.

**** * Step 5. After successfully passing the cycling test, the cylinder shall be burst tested in accordance with the procedure described in CFFC-10(b)(i) of this standard.

*(ii) **Acceptable test results**: Each test cylinder must withstand the cycling pressurization test without any evidence of visually observable damage, distortion or leakage. In addition, the residual burst strength of the cylinder must be at least 90 percent of the required minimum burst pressure (3.06 times service pressure). The outer surface of the liner must show no evidence of corrosion or defects such as cracking, leakage, etc.

(f) **Thermal cycling test**: Two cylinders shall be cycle tested in accordance with the following:

(i) **Procedure:** The cycling rate may not exceed 10 cycles per minute. The dwell time between 90 and 100 percent of the maximum test pressure may not be less than 1.2 seconds.

Step 1. Cycle test at ambient temperature by pressurizing from approximately zero pressure to service pressure for 10,000 cycles.

*** Step 2. Pressurize and maintain the cylinder at service pressure and subject the cylinder to a minimum of 20 thermal cycles at each temperature of 93.3°C (200^0F) and minus 51.6°C (minus 60^0F) maintaining the dwell time at each extreme temperature to a minimum of 10 minutes.

**** Step 3. After successfully passing the cycling test, the cylinder shall be burst tested in accordance with the procedure described in CFFC-10(b)(i) of this standard.

(ii) **Acceptable test results**: The test cylinder must withstand the thermal cycling test without any evidence of visually observable damage, distortion or leakage. In addition, the residual burst strength of the cylinder must be at least 90 percent of the required minimum burst pressure

(3.06 times service pressure).

(g) **Gunfire test**: One cylinder must be tested in accordance with the following:

(i) **Procedure:** The cylinder must be charged with air or nitrogen to service pressure and shall be impacted by a 0.30 caliber armor piercing projectile having a velocity of about 853.4 meters (2800 feet) per second. The cylinder shall be positioned in such a way that the impact point shall be in the cylinder sidewall at an angle of 45^0 to the longitudinal axis of the cylinder and aimed to exit the sidewall on the opposite side of the cylinder. The distance from the firing location to the cylinder may not exceed 45.7 meters (150 feet).

(ii) **Acceptable test results**: The cylinder shall not fail by fragmentation. The approximate size of the entrance and exit penetrations shall be recorded.

(h) **Bonfire test**: Two cylinders must be tested in accordance with the following:

(i) **Procedure:** Cylinders must be fitted with the valves and pressure relief devices as specified in CFFC-8 of this standard, set to discharge at a pressure between 83 percent and 100 percent of the cylinder test pressure at ambient conditions. Cylinders must be charged with nitrogen or air to service pressure. The required bonfire test procedure shall be in accordance with the Compressed Gas Association (CGA) Pamphlet CGA C-14-1992. The test shall be performed with the cylinder placed in an upright position. The cylinder shall be exposed to fire until the contents are fully vented.

(ii) **Acceptable test results**: The venting of the gas must be predominantly through the pressure relief device. Cylinders must be intact at the completion of venting.

******** CFFC-11 **<u>QUALIFICATION REQUIREMENTS FOR DESIGN CHANGE</u>**: Cylinders representative of each design and design change (from the original design) must be subjected to the following qualification tests and stress analysis:

Type of Test or Requirement	Original Design	DESIGN CHANGE						
		Material	Diameter or Service Pressure		Water capacity		Manufacturing Facility	Liner
		Any Change	10 to 20 percent change	Greater than 20 percent change	30 to 50 percent change	Greater than 50 percent change	Any Change	Reduction in dome or wall thickness
Resin Shear Test	X	X	-	-	-	-	-	-
Cycling-Ambient Temp.	X	X	X	X	X	X	X	X
Cycling-Environmental	X	X	-	X	-	X	X	-
Cycling-Thermal	X	X	-	X	-	X	X	-
Hydrostatic Burst	X	X	X	X	X	X	X	X
Gunfire	X	X	X	X	X	X	X	-
Bonfire	X	X	X	X	X	X	X	-
* Drop Test	X	X	X	X	X	X	X	X
Stress Analysis	X	X	X	X	-	X	-	X

X = Applies - = Does not apply

CFFC-12 **<u>MANUFACTURING, QUALITY ASSURANCE, AND LOT QUALIFICATION TESTS</u>**:

(a) **Manufacturing:**

(i) The manufacturer is responsible for total compliance with this standard and as prescribed in the DOT exemption.

**** (ii) All materials, manufacturing equipment types, fabrication processes, and quality control procedures for production cylinders shall conform in all aspects with those used in the manufacture of the cylinders used in design qualification tests.

(iii) The manufacturer shall retain production data, including lot qualification test results for each lot of 200 cylinders successively produced, and retain the records for the cylinder's approved service life.

(b) **Quality Control Procedures**:

(i) The manufacturer shall establish and maintain for each design type a documented quality assurance system described fully with control features in a quality manual.

(ii) The manufacturer shall establish procedures for compliance with all control features to the satisfaction of the independent inspector.

(c) **Lot definition:**

(i) Completed cylinders: A "lot" means a group of cylinders successively produced as completed cylinders.

(ii) Unless approved in writing by AAHMS, in no case shall the lot size exceed 200 cylinders excluding the cylinders used for lot qualification tests.

(d) **Lot qualification tests**: For each lot of completed cylinders, qualification tests as prescribed herein shall be performed with satisfactory results.

(i) **Burst test:** One cylinder (randomly selected) from each lot of completed cylinders must be hydrostatically tested in accordance with the following:

(A) **Procedure:** Cylinder must be tested in accordance with CFFC-10(b)(i) of this

standard. A cylinder used in the cycling test may be used for the burst test.

(B) **Acceptable test results**: The measured burst pressure may not be less than the minimum required burst pressure. Failure must initiate in the cylinder sidewall.

(ii) **Ambient temperature cycling pressurization tests:** One cylinder (randomly selected) from each lot of completed cylinders must be subjected to cyclic pressurization testing in accordance with the following:

(A) **Procedure:** The cylinder shall be cycled to service pressure in accordance with CFFC-10(d)(i) of this standard. Adequate recording instrumentation must be provided if the test is expected to run unattended for any period of time exceeding two hours.

(B) **Acceptable test results**: Test results must be in accordance with CFFC-10(d)(ii) of this standard.

(e) **Lot acceptance criteria**:

(i) All cylinders in a lot that did not meet the required lot qualification test results must be rejected.

(ii) However, when a cylinder fails a test, five additional cylinders selected randomly may be subjected to the same test. If all five cylinders pass, the lot may be accepted. If one or more of the cylinders fails, the lot must be rejected.

CFFC-13 **PRODUCTION TESTS**: The following nondestructive tests and inspections shall be performed on all completed cylinders in each lot.

(a) **Hydrostatic test**. Each cylinder must be hydrostatically pressurized to test pressure after the cylinder has been autofrettaged. The test pressure must be maintained for a minimum of 60 seconds and as much longer as may be necessary to ensure stable volumetric expansion. The elastic and total volumetric expansions must be determined. Cylinders that show evidence of leakage or distortion must be rejected.

(i) The hydrostatic test must be by the water jacket method. The system must be calibrated

and operated so as to obtain accurate data. The pressure reading must be accurate within one percent in the range of 80 percent to 120 percent of the test pressure, and the volumetric expansion measurement must be accurate to within one percent of the total expansion established when in system calibration, or 0.1 cubic centimeter. Records must be maintained as evidence of the equipment calibration.

*****(ii) The hydrostatic test system must be calibrated at the beginning of each day prior to testing using a Calibrated Cylinder following procedures specified in CGA pamphlet C-1 “Methods of Hydrostatic Testing of Compressed Gas Cylinders."

(b) **Visual inspection and marking**: All cylinders in each lot must be subjected to a thorough visual inspection for quality and for conformance with the marking requirements.

CFFC-14 **MARKING:**

(a) Each cylinder that is made in conformance with this standard and the applicable DOT exemption must be permanently marked (other than stamping) in the composite overwrap on the sidewall. The marking must be easily visible and must be protected from external damage due to the environment and handling.

(b) The details of the marking must conform to the requirements of this standard and the DOT exemption under which the cylinders are manufactured. The marking must contain the following:

(i) DOT Exemption number (DOT E-XXXXX) followed by service pressure expressed in pounds per square inch gauge (psig).

(ii) A serial number and the manufacturer's identification number or a symbol as obtained from the Associate Administrator for Hazardous Materials safety, located just below or immediately following the DOT marking above.

(iii) The DOT inspector’s official mark must be placed near the serial number. The marking must contain date (month and year) of the initial hydrostatic test for that cylinder.

***** (iv) Rejection elastic expansion (REE) marking in cubic centimeters. The REE for each design type cylinder is obtained as follows:

1. Perform hydrostatic testing on a lot of cylinders and record elastic expansion (EE) of each cylinder.

2. Find the mean value of the EE for all cylinders tested in item 1.

3. Mark each cylinder with REE which is less than or equal to 10% above the mean value obtained in item 2.

(v) The size of the letters and numbers used must be at least 0.64cm (1/4 inch) high if space permits.

(vi) The following are the authorized formats for marking:

DOT- E xxxxx-PPPP
1234-MMI (or symbol)
II-MM/YY REE

and,DOT-E xxxxx-PPPP-1234-MMI-MM/YY REE NNN

(vii) Additional markings are permitted in the composite, provided the additional markings do not obscure the required markings and are not detrimental to the integrity of the cylinder.

(vii) Provisions for marking of the required retest dates and retester information must be made near the cylinder markings.

CFFC-15 **INSPECTOR'S REPORTS:**

(a) The inspector must prepare a report that is clear, legible and in accordance with the following form:

REPORT OF MANUFACTURE OF CARBON FIBER REINFORCED PLASTIC FULL COMPOSITE CYLINDERS (CFFC)

(Place) _____
(Date) _____
(Exemption number) _____
Manufactured for _____
Company.
Located at _____
Manufactured by _____
Company.
Located at _____
Consigned to _____
Company.
Located at _____
___Quantity _____ Size _____ inches outside diameter by _____ _ inches long

Marking placed on the _____ of the cylinder is:

DOT-E _____
Serial numbers _____ to _____
inclusive.
Identifying symbol (Registered) _____
Inspector's mark (Registered) _____
Test date(s) _____
Other marks (if any) _____
___

Each composite cylinder was made by completely over wrapping a seamless aluminum liner with resin impregnated filament reinforcement. Composite overwrap was made by winding resin impregnated _____ continuous filament over this liner in both longitudinal and circumferential directions, followed by curing the resin at controlled temperature.

The aluminum liner was identified by heat numbers and verified as to chemical analysis, record thereof is attached hereto. Liners fabricated from the aluminum were solution heat treated and artificially aged to T-6 temper. Physical tests were made in the presence of the inspector and report of test results is attached hereto.

Each liner was inspected before and after closing in the ends. All that were inspected were found to be free from seams, cracks, laminations and other defects which might prove injurious to the strength of the cylinder.

Liner walls were measured and the minimum thickness noted was at least equal to the minimum design thickness. The outside diameter was found by a close approximation to be _____ inches.

Filament and resin were certified by the manufacturers, and identified by package number. Filament was verified as to strand strength. Composite was verified as to shear strength. After wrapping, composite was cured per manufacturers's specification.

Prescribed autofrettage and hydrostatic tests were made in the presence of the inspector. All cylinders accepted conform with the specification requirements. Results of autofrettage and hydrostatic tests are attached hereto.

Tensile stress on the aluminum liner in the hoop direction is calculated to be _____psi at service pressure. Carbon fiber stress is calculated to be_____psi in the hoop direction and _____ psi in the longitudinal direction at service pressure.

I hereby certify that all of these cylinders proved satisfactory in every way and conform with the requirements of DOT-E _____ ; except as follows:

Exceptions taken to any reporting or testing requirements of this exemption are: _____
_____
_____
_____.

(Signed) _____
(Inspector)

RECORD OF CHEMICAL ANALYSES OF MATERIAL FOR LINER

(Place) _____(Date) _____
(Exemption number) _____
Serial numbers _____ to _____ inclusive.
Size _____ inches outside diameter by _____ inches long.
Made by _____ Company.
For _____ Company.
Material description _____
_____.

NOTE: Any omission of analyses by heats, if authorized, must be accounted for by notation herein reading "The prescribed certificate of the manufacturer of material has been secured, found satisfactory, and placed on file." or by attaching a copy of the certificate.

Alloy Designation (Per Aluminum Assoc.)	Cylinders Represented (Serial Nos.)	Chemical Analysis												
												Others		
		Si	Fe	Cu	Mn	Mg	Cr	Pb	Bi	Zn	Ti	Each	Total	Al
														Remainder

Material was manufactured and mill analyses made by _____. Originals of the certified mill analyses reports are in files of the material manufacturer.

(Signed) _____
(Inspector)

RECORD OF PHYSICAL TESTS OF MATERIAL FOR LINERS.

(Place) _____(Date) _____
(Exemption Number) _____
Serial numbers _____ to _____ inclusive.
Size _____ inches outside diameter by _____ inches long.
Made by _____ Company

For _____ Company
Test specimen description _____

Lot Code	Cylinders Represented by test (Serial Numbers)	Yield strength at 0.2 percent offset (psi)	Tensile strength (psi)	Elongation (percent)

(Signed) _____
(Inspector)

REPORT OF COMPOSITE ANALYSES

(Place) _____ (Date) _____
(Exemption number) _____
Materials _____
Manufactured by _____ Company
For _____ Company
Numbered _____
Filament specification and designation _____
Manufactured by _____ Company

****

Filament materials

Manufacturing Package Number	Tensile Strength

RESIN SYSTEM COMPONENTS
MANUFACTURING BATCH NUMBERS

Resin			Curing Agent		Accelerator	
Batch Number	Type	Interlaminar Shear Strength	Batch Number	Type	Batch Number	Type

Signed _____
(Inspector)

REPORT OF HYDROSTATIC TEST FOR CFFC TYPE CYLINDERS

(Place) _____ (Date) _____
(Exemption number) _____
Manufactured by: _____
Located at: _____

Manufactured for: _____
Located at: _____
Serial numbers: _____ to _____ inclusive.
Symbol _____
Minimum prescribed test pressure _____ psig.
****

Serial No.	Weight (lbs) (without valve)			Vol (in^3)	Autofrettage		HYDROSTATIC TEST		
	Liner	Comp-osite	Total		Press (Psi)	Total Expan-sion (CC)	Elast. Expan-sion (CC)	Actual Test Press.	Total Expan-sion (CC)

LOT CYCLING AND BURST TESTS				
Type of Test	Serial Number of Cylinder	Number of Pressurization		Burst Pressure (psig)
		To Service Pressure	To Test Pressure	
Cycling				
Virgin Burst				

Signed:_____
(Inspector)

CFFC-16 **RETENTION OF REPORTS:** The inspector's report (CFFC-15) must be retained for the approved service life of the cylinder by the maker and the inspector.