

# **Guide: Space Systems — Composite Overwrapped Pressure Vessels with a Plastic Liner**

AIAA standards are copyrighted by the American Institute of Aeronautics and Astronautics (AIAA), 12700 Sunrise Valley Drive, Suite 200, Reston, VA 20191-5807 USA. All rights reserved.

AIAA grants you a license as follows: The right to download an electronic file of this AIAA standard for storage on one computer for purposes of viewing, and/or printing one copy of the AIAA standard for individual use. Neither the electronic file nor the hard copy print may be reproduced in any way. In addition, the electronic file may not be distributed elsewhere over computer networks or otherwise. The hard copy print may only be distributed to other employees for their internal use within your organization.

# **Guide: Space Systems — Composite Overwrapped Pressure Vessels with a Plastic Liner**

## **Sponsored and Approved by**

American Institute of Aeronautics and Astronautics

## **Approved**

6 December 2022

## **Abstract**

This Guide assists in establishing baseline requirements for the design, analysis, fabrication, test, inspection, operation, and maintenance of composite overwrapped pressure vessels (COPVs) with a plastic non-metallic liner. These COPVs are used for pressurized, hazardous, or nonhazardous liquid or gas storage in space systems including spacecraft and launch vehicles. This Guide is applicable to COPVs constructed with a plastic liner and a carbon fiber/polymer overwrap.

Published by  
**American Institute of Aeronautics and Astronautics**  
**12700 Sunrise Valley Drive, Suite 200, Reston, VA 20191**

Copyright © 2023 American Institute of Aeronautics and  
Astronautics  
All rights reserved.

No part of this publication may be reproduced in any form, in an electronic retrieval  
system or otherwise, without prior written permission of the publisher.

Printed in the United States of America

ISBN 978-1-62410-706-1

## Contents

|          |                                                               |           |
|----------|---------------------------------------------------------------|-----------|
| <b>1</b> | <b>Scope .....</b>                                            | <b>1</b>  |
| 1.1      | Purpose .....                                                 | 1         |
| 1.2      | Applicability .....                                           | 1         |
| 1.3      | Designation of Responsibilities.....                          | 1         |
| 1.3.1    | Owner .....                                                   | 1         |
| 1.3.2    | Procuring Authority .....                                     | 2         |
| 1.3.3    | Manufacturer.....                                             | 2         |
| <b>2</b> | <b>Tailoring.....</b>                                         | <b>2</b>  |
| <b>3</b> | <b>Applicable Documents .....</b>                             | <b>3</b>  |
| <b>4</b> | <b>Vocabulary .....</b>                                       | <b>5</b>  |
| 4.1      | Acronyms and Abbreviated Terms.....                           | 5         |
| 4.2      | Terms and Definitions .....                                   | 6         |
| <b>5</b> | <b>General Design .....</b>                                   | <b>13</b> |
| 5.1      | System Analysis .....                                         | 13        |
| 5.1.1    | Reserved .....                                                | 13        |
| 5.1.2    | Reserved .....                                                | 13        |
| 5.1.3    | Maximum Expected Operating Pressure.....                      | 13        |
| 5.1.4    | Maximum External Pressure Differential .....                  | 13        |
| 5.1.5    | Load, Acoustic, Shock, and Vibration Environment .....        | 13        |
| 5.1.6    | Service Life .....                                            | 14        |
| 5.1.7    | Volume Capacity .....                                         | 14        |
| 5.1.8    | Reserved .....                                                | 14        |
| 5.1.9    | Physical Envelope.....                                        | 14        |
| 5.1.10   | Acceptable Leak Rate .....                                    | 14        |
| 5.1.11   | Mass .....                                                    | 14        |
| 5.1.12   | Cleanliness Level.....                                        | 14        |
| 5.1.13   | Fluids .....                                                  | 15        |
| 5.1.14   | Shipping Environment.....                                     | 15        |
| 5.1.15   | Mechanical Damage Environment .....                           | 15        |
| 5.1.16   | Thermal Environment.....                                      | 15        |
| 5.1.17   | Unique Operating Environments .....                           | 15        |
| 5.1.18   | Reliability .....                                             | 15        |
| 5.1.19   | Electrical Conductivity .....                                 | 15        |
| 5.2      | Composite Overwrapped Pressure Vessel Design Parameters ..... | 15        |
| 5.2.1    | Burst Factor .....                                            | 15        |
| 5.2.2    | Design Burst Pressure .....                                   | 16        |
| 5.2.3    | Proof Pressure .....                                          | 16        |
| 5.2.4    | Design Safety Factor .....                                    | 17        |
| 5.2.5    | Margin of Safety.....                                         | 17        |
| 5.2.6    | Negative Pressure Differential Design.....                    | 17        |
| 5.2.7    | Volume Capacity Design.....                                   | 18        |
| 5.2.8    | Physical Envelope Design.....                                 | 18        |
| 5.2.9    | Mass Design .....                                             | 18        |
| 5.2.10   | Structural Stability Design .....                             | 18        |
| 5.2.10.1 | Structural Stability Design, COPV .....                       | 18        |
| 5.2.10.2 | Structural Stability Design, Liner .....                      | 18        |
| 5.2.11   | Fluid Compatibility Design.....                               | 19        |

|            |                                                                          |           |
|------------|--------------------------------------------------------------------------|-----------|
| 5.2.12     | Load, Acoustic, Shock, and Vibration Environment Design .....            | 19        |
| 5.2.13     | Fracture Control Design .....                                            | 19        |
| 5.2.13.1   | Damage Tolerance Life, Metallic Portion of the Liner, Design .....       | 19        |
| 5.2.13.2   | Reserved .....                                                           | 20        |
| 5.2.13.3   | Damage Tolerance Life, Plastic Portion of the Liner, Design .....        | 20        |
| 5.2.14     | Fatigue Life Design .....                                                | 20        |
| 5.2.15     | Stress Rupture Design .....                                              | 20        |
| 5.2.16     | Unique Operating Environments Design .....                               | 20        |
| 5.2.17     | Reserved .....                                                           | 21        |
| 5.2.18     | Reserved .....                                                           | 21        |
| 5.2.19     | Reserved .....                                                           | 21        |
| 5.2.20     | Reserved .....                                                           | 21        |
| 5.2.21     | Reserved .....                                                           | 21        |
| 5.2.22     | Reliability Design .....                                                 | 21        |
| 5.2.23     | Electrical Conductivity Design .....                                     | 21        |
| 5.2.24     | Materials and Thermal Compatibility Design .....                         | 21        |
| 5.2.25     | Permeation Rate Design .....                                             | 21        |
| <b>5.3</b> | <b>Damage Control Plan .....</b>                                         | <b>21</b> |
| <b>5.4</b> | <b>Materials .....</b>                                                   | <b>22</b> |
| <b>6</b>   | <b>General Verification .....</b>                                        | <b>22</b> |
| <b>6.1</b> | <b>Structural Stability Verification .....</b>                           | <b>22</b> |
| <b>6.2</b> | <b>Fracture Control Verification .....</b>                               | <b>22</b> |
| 6.2.1      | Damage Tolerance Life, Metallic Portion of the Liner, Verification ..... | 22        |
| 6.2.2      | Reserved .....                                                           | 23        |
| <b>6.3</b> | <b>Unique Operating Environments Verification .....</b>                  | <b>23</b> |
| <b>7</b>   | <b>Verification by Analysis .....</b>                                    | <b>23</b> |
| <b>7.1</b> | <b>Metallic Material Properties .....</b>                                | <b>23</b> |
| <b>7.2</b> | <b>Composite and Plastic Material Properties .....</b>                   | <b>24</b> |
| 7.2.1      | Composite Material Properties, Composite Overwrap .....                  | 24        |
| 7.2.2      | Plastic Material Properties, Liner .....                                 | 25        |
| 7.2.3      | Material Properties, Bonded Joints .....                                 | 26        |
| <b>7.3</b> | <b>Analysis Model .....</b>                                              | <b>26</b> |
| 7.3.1      | Analysis Model – Strength .....                                          | 26        |
| 7.3.2      | Analysis Model – Loads .....                                             | 27        |
| 7.3.3      | Analysis Model – Liner .....                                             | 27        |
| 7.3.4      | Analysis Model – Overwrap .....                                          | 27        |
| 7.3.5      | Analysis Model – Stiffness .....                                         | 27        |
| 7.3.6      | Analysis Model – Thermal Effects .....                                   | 27        |
| <b>7.4</b> | <b>COPV Analysis .....</b>                                               | <b>27</b> |
| 7.4.1      | Proof Pressure Analysis .....                                            | 27        |
| 7.4.2      | Design Burst Pressure Analysis .....                                     | 28        |
| 7.4.3      | Margin of Safety Analysis .....                                          | 28        |
| 7.4.4      | Negative Pressure Differential Analysis .....                            | 28        |
| 7.4.5      | Structural Stability Analysis .....                                      | 28        |
| 7.4.5.1    | Linear Buckling Analysis .....                                           | 29        |
| 7.4.5.2    | Nonlinear Buckling Analysis .....                                        | 29        |
| 7.4.6      | Volume Capacity Analysis .....                                           | 29        |
| 7.4.7      | Physical Envelope Analysis .....                                         | 29        |
| 7.4.8      | Mass Analysis .....                                                      | 30        |

|             |                                                                                   |           |
|-------------|-----------------------------------------------------------------------------------|-----------|
| 7.4.9       | Load, Acoustic, Shock, and Vibration Environment Analysis .....                   | 30        |
| 7.4.10      | Unique Operating Environments Analysis .....                                      | 30        |
| 7.4.11      | Fluid Compatibility Analysis .....                                                | 30        |
| 7.4.12      | Fatigue Life Analysis .....                                                       | 30        |
| 7.4.13      | Stress Rupture Analysis .....                                                     | 31        |
| 7.4.14      | Damage Control Plan Analysis .....                                                | 31        |
| 7.4.15      | Reserved .....                                                                    | 31        |
| 7.4.16      | Reserved .....                                                                    | 31        |
| 7.4.17      | Reserved .....                                                                    | 31        |
| 7.4.18      | Reserved .....                                                                    | 31        |
| 7.4.19      | Electrical Conductivity Analysis .....                                            | 31        |
| 7.4.20      | Permeation Analysis .....                                                         | 31        |
| <b>7.5</b>  | <b>Fracture Control Analysis .....</b>                                            | <b>32</b> |
| 7.5.1       | Damage Tolerance Life, Metallic Portion of the Liner, Analysis .....              | 32        |
| 7.5.2       | Reserved .....                                                                    | 33        |
| <b>7.6</b>  | <b>Reliability Engineering Analysis .....</b>                                     | <b>33</b> |
| 7.6.1       | Reliability Analysis .....                                                        | 33        |
| 7.6.2       | Failure Modes and Effects Analysis .....                                          | 33        |
| <b>8</b>    | <b>Manufacturing .....</b>                                                        | <b>33</b> |
| 8.1         | Process Control .....                                                             | 33        |
| 8.2         | Corrosion Control and Fluid Compatibility .....                                   | 33        |
| 8.3         | Embrittlement Control .....                                                       | 34        |
| 8.4         | Liner Fabrication and Process Control .....                                       | 34        |
| 8.5         | Overwrap Fabrication and Process Control .....                                    | 34        |
| <b>9</b>    | <b>Quality Assurance .....</b>                                                    | <b>34</b> |
| 9.1         | QA Program Procedures .....                                                       | 34        |
| 9.2         | Quality Plan .....                                                                | 34        |
| 9.3         | Qualification Plan .....                                                          | 35        |
| 9.4         | Acceptance Plan .....                                                             | 35        |
| 9.5         | Inspection and Test Plan .....                                                    | 35        |
| 9.5.1       | Inspection and Test Plan - Liner .....                                            | 35        |
| 9.5.2       | Inspection and Test Plan - Composite Overwrap .....                               | 36        |
| 9.6         | Inspector Qualification and Certification .....                                   | 36        |
| 9.6.1       | Inspector Qualification, Liner .....                                              | 36        |
| 9.6.2       | Inspector Qualification, Composite Overwrap .....                                 | 36        |
| 9.6.3       | Inspector Certification .....                                                     | 36        |
| 9.7         | Quality Documentation .....                                                       | 36        |
| <b>10</b>   | <b>Verification by Test .....</b>                                                 | <b>37</b> |
| <b>10.1</b> | <b>Damage Tolerance Life, Test .....</b>                                          | <b>37</b> |
| 10.1.1      | Damage Tolerance Life, Metallic Portion of the Liner, Test—Coupon Specimens<br>37 |           |
| 10.1.2      | Damage Tolerance Life, Metallic Portion of the Liner, Test—COPV Specimens         | 38        |
| 10.1.3      | Damage Tolerance Life, Plastic Portion of the Liner, Test—COPV Specimens          | 39        |
| 10.1.4      | Damage Tolerance Life Pressure Cycle Test .....                                   | 41        |
| <b>10.2</b> | <b>Reserved .....</b>                                                             | <b>41</b> |
| <b>10.3</b> | <b>Damage Control Test .....</b>                                                  | <b>41</b> |
| 10.3.1      | Worst-case threat damage tolerance life testing .....                             | 41        |
| 10.3.2      | Visual mechanical damage threshold testing .....                                  | 42        |
| 10.3.3      | Protective cover testing .....                                                    | 42        |

|             |                                                                        |           |
|-------------|------------------------------------------------------------------------|-----------|
| 10.3.4      | Damage indicator testing .....                                         | 42        |
| <b>10.4</b> | <b>Qualification Test .....</b>                                        | <b>43</b> |
| 10.4.1      | Qualification Test Instrumentation .....                               | 45        |
| 10.4.2      | Nondestructive Testing .....                                           | 45        |
| 10.4.3      | Physical Envelope Test.....                                            | 46        |
| 10.4.4      | Mass Test .....                                                        | 46        |
| 10.4.5      | Volume Capacity Test.....                                              | 46        |
| 10.4.6      | Proof Test .....                                                       | 46        |
| 10.4.7      | Leak Test.....                                                         | 46        |
| 10.4.8      | Pressure Cycle Test.....                                               | 46        |
| 10.4.9      | Load, Acoustic, Shock, Vibration, and External Loads Test .....        | 47        |
| 10.4.10     | Unique Operating Environments Test .....                               | 47        |
| 10.4.11     | Burst Test .....                                                       | 47        |
| 10.4.12     | Stability Test .....                                                   | 48        |
| 10.4.13     | Reserved .....                                                         | 48        |
| 10.4.14     | Negative Pressure Differential Test.....                               | 48        |
| 10.4.15     | Permeation Test .....                                                  | 48        |
| <b>10.5</b> | <b>Validation of Analysis Model with Qualification Test Data .....</b> | <b>48</b> |
| <b>10.6</b> | <b>Acceptance Tests .....</b>                                          | <b>49</b> |
| 10.6.1      | Structural Proof Load Test .....                                       | 50        |
| 10.6.2      | Acceptance Volume Capacity Test .....                                  | 50        |
| <b>11</b>   | <b>Operations and Maintenance .....</b>                                | <b>51</b> |
| 11.1        | Operating Procedures .....                                             | 51        |
| 11.2        | Safe Operating Limits.....                                             | 51        |
| 11.3        | Special Requirements for Pressurized COPVs.....                        | 51        |
| 11.4        | Embrittlement Control.....                                             | 52        |
| 11.5        | Inspection and Maintenance.....                                        | 52        |
| 11.6        | Material Review Board .....                                            | 52        |
| 11.7        | Repair and Refurbishment.....                                          | 52        |
| 11.8        | Storage.....                                                           | 52        |
| 11.9        | Operations Documentation.....                                          | 53        |
| <b>12</b>   | <b>Documentation Retention .....</b>                                   | <b>53</b> |
|             | <b>Annex (Informative) .....</b>                                       | <b>54</b> |

## Tables

Table 1 — Determination of Burst Factor, Proof Factor, Negative Pressure Factor, and Design Safety Factor ..... 17

Table 2 — Design Requirements Verification Matrix..... 54

Figures

FIGURE 1 - REPRESENTATIVE FLOW CHART FOR VERIFICATION BY TEST OF DAMAGE TOLERANCE LIFE, PLASTIC PORTION OF THE LINER.....40

FIGURE 2 — REPRESENTATIVE FLOW CHART FOR A QUALIFICATION TEST PROGRAM. NOTE THAT THE ACCEPTANCE TEST PROGRAM IS PART OF THIS OVERALL TEST PROGRAM AND IS INDICATED BY THE BOX.....44

FIGURE 3 — REPRESENTATIVE FLOW CHART FOR AN ACCEPTANCE TEST PROGRAM.....50

## Foreword

This Guide is sponsored by the American Institute of Aeronautics and Astronautics (AIAA) as part of its Standards Program.

This Guide was developed in collaboration with manufacturers, launch site operators, range safety authorities, and individuals affiliated with universities and government entities.

The AIAA Aerospace Pressure Vessels (APV) Committee on Standards (CoS) was initially formed in March 1996 as a working group within the AIAA Structures Committee on Standards with an emphasis on inclusion of aerospace prime companies, pressure vessel suppliers, and all applicable government agencies. Deliberations focused on adapting the standard to address commercial procurement of aerospace composite pressure vessels.

The APV CoS in 2018 published: ANSI/AIAA S-080A-2018 Space Systems—Metallic Pressure Vessels, Pressurized Structures, and Pressure Components (Revision of AIAA S-080-1998) and ANSI/AIAA S-081B-2018 Space Systems—Composite Overwrapped Pressure Vessels (Revision of AIAA S-081A-2006). These two standards followed a consistent numbering; sections (requirements) that are common between the two have the same number in both documents. If one document has a section (requirement) that is not applicable (while it is relevant for the companion document) then the section is marked reserved to keep the numbering consistent. The same consistency has been followed in this Guide with respect to the two other standards.

ANSI/AIAA S-081B-2018 is applicable to COPVs constructed with a metal liner and a carbon fiber/polymer overwrap. The incorporation of a non-metallic liner changes the approach to certifying this class of COPVs and necessitates a distinct set of baseline requirements. Because the technology associated with the use of these COPVs has not been used extensively in space applications, the AIAA Aerospace Pressure Vessel Committee on Standards decided to develop this Guide in order to establish the framework for such requirements. It is hoped that this Guide will develop into a standard as the industry adopts the usage of these vessels and a consensus set of requirements emerges.

The AIAA Standards Program Procedures defines a Guide as:

technical information that supports present or future Standards or Recommended Practices and provides instruction for their application; this category includes handbooks and uses “may” statements, indicating a permissive position

In this Guide, the requirements that are retained from ANSI/AIAA S-081B-2018 are indicated with Asterisks, i.e., they are expressed as “\*may\*” statements. It is noted that ANSI/AIAA S-080A-2018 and ANSI/AIAA S-081B-2018 follow the same document structure, so this Guide matches the organization of these two standards.

The Guide includes new sections to provide guidance for establishing design and verification requirements related to the non-metallic liner.

In general, the committee chose not to update sections of the document not affected by the change of the liner material. In some areas, it was felt necessary to offer improvements based on experience. The following changes to baseline requirements are included:

- Additional clarification was provided for the use of the Environmental Correction Factor (ECF).
- Definitions were updated. Definitions were added for liner, hydrogen embrittlement, and glass transition temperature.
- Requirements for reliability were added as they appear to be an error in the previous standards.

It is anticipated that these changes might later be incorporated into future revisions of ANSI/AIAA S-080A-2018 and ANSI/AIAA S-081B-2018.

We are indebted to those authors who served on the Drafting Committee and compiled the input from a broad range of stakeholders to form the various drafts for review by the committee: Jim Harris (Editor/Chair), Jacob Fannon, Scott Forth, Vinal Goyal, and Michael Kezirian.

The current members of the AIAA APV CoS appreciate the valuable input from several original members and express their gratitude to past committee members and reviewers whose contributions over many years have resulted in an improved standard. At the time of approval of this document, members of the APV CoS were:

|                            |                                   |
|----------------------------|-----------------------------------|
| Michael Kezirian, Chair    | University of Southern California |
| Nathanael Greene, Co-Chair | NASA Johnson Space Center         |
| Alejandro Vega, Co-Chair   | U.S. Air Force                    |

Members:

|                          |                                                        |
|--------------------------|--------------------------------------------------------|
| Pravin Aggarwal*         | Independent Consultant                                 |
| Clifton Arnold           | NASA OSMA                                              |
| Robert Biggs             | Lockheed Martin Space Systems Company                  |
| Dan Bryan                | MCET Technologies                                      |
| James Cannon             | Axiom Space                                            |
| Kevin Case               | USAF, 30th Space Wing Safety                           |
| Jim Chang                | Analytical Mechanics Associates                        |
| Gregory Coll             | Northrop Grumman                                       |
| Robert Conger            | Microcosm, Inc.                                        |
| Harry Conomos            | Moog Inc.                                              |
| Adam Cooper              | NASA Kennedy Space Center                              |
| John Duke, Jr.*          | Virginia Polytechnic Institute and State University    |
| Amy Engelbrecht-Wiggans* | Cornell University                                     |
| Paul Fabian              | Composite Technology Development, Inc.                 |
| Jacob Fannon             | Blue Origin                                            |
| Scott Forth              | Space Exploration Technologies Corporation             |
| Susan Gavin              | Independent Technical Advisor - Engineering Contractor |
| Wes Geiman               | Vivace Corporation                                     |
| David Gillis             | Airbus                                                 |
| Vinay Goyal              | The Aerospace Corporation                              |
| Owen Greulich            | Consultant                                             |
| Jonathan Griffith        | Marotta Controls                                       |

|                       |                                                |
|-----------------------|------------------------------------------------|
| Lorie Grimes-Ledesma  | NASA Jet Propulsion Laboratory                 |
| Tim Gurshin*          | Lockheed Martin Space Systems Company          |
| Ches Hall*            | NASA TOSC                                      |
| Joe Hamilton          | Engineering Research Consulting, Inc           |
| Jim Harris            | Hexagon MasterWorks, Inc.                      |
| Luis Hernandez        | Jacobs Technology                              |
| Mike Holt             | Virgin Orbit                                   |
| Kauser Imtiaz         | NASA Johnson Space Center                      |
| Srinath Iyengar       | Independent Consultant                         |
| Ian Juby              | NASA Johnson Space Center                      |
| Junaid Karim          | Axiom Space                                    |
| Michael Kelly*        | Independent Consultant                         |
| Peter Kinsman         | Aerojet Rocketdyne                             |
| Scott Kramer          | NASA Marshall Space Flight Center              |
| Aaron Laney           | Jacobs Technology                              |
| Edward Lira           | USAF, 30th Space Wing Safety                   |
| Efren Luevano         | Infinite Composites Technologies               |
| Kaushik Mallick       | Verne                                          |
| David McColskey       | National Institute of Standards and Technology |
| Dan Mueller*          | Independent Consultant                         |
| Cornelius Murray      | General Dynamics / OTS                         |
| Norman Newhouse       | Newhouse Technology LLC                        |
| Yenyih Ni             | The Aerospace Corporation                      |
| Jay Nightingale       | Lockheed Martin Space Systems Company          |
| Michael Papadopoulos* | The Aerospace Corporation                      |
| James Patterson       | HyPerComp Engineering                          |
| Allyssa Paul*         | The Aerospace Corporation                      |
| Henry Peebles         | USAF 45th Space Wing (Range Safety - KSC)      |
| Mark Pokrywka         | Vivace Corporation                             |
| Xueyong Qu            | The Aerospace Corporation                      |
| Jeff Rayburn          | NASA Marshall Space Flight Center              |
| Kevin Richards        | Northrop Grumman Innovation Systems            |

|                         |                                           |
|-------------------------|-------------------------------------------|
| Markus Rufer            | Scorpius Space Launch Company             |
| Rick Russell*           | NASA KSC                                  |
| Christopher Sagrillo    | The Aerospace Corporation                 |
| Laura Sargent           | USAF 45th Space Wing (Range Safety - KSC) |
| Christian Schumacher    | Naval Undersea Warfare Center             |
| Kay Siegel              | H2Safe, LLC                               |
| Gerben Sinnema          | European Space Agency                     |
| Tucker Smith            | HyPerComp Engineering                     |
| Kirk Sneddon            | Arde, Inc.                                |
| Brett Soltz             | The Aerospace Corporation                 |
| Michael Sonnen          | ETC Deutschland                           |
| Brian Spencer*          | Spencer Composites                        |
| Mark Stevens            | MEI Technologies                          |
| Jim Sutter*             | Independent Consultant                    |
| Pete Taddie*            | NASA KSC                                  |
| John Thesken*           | NASA Glenn Research Center                |
| Daryl Thompson          | HyPerComp Engineering                     |
| Matt Villarreal         | Infinite Composites Technologies          |
| Enzo Vito               | Axiom Space                               |
| Le-Son Vu Hoang-Mazière | ArianeGroup                               |
| Jake Walker             | HyPerComp Engineering                     |
| Jess Waller             | New Mexico State University               |
| Daniel Wentzel*         | NASA White Sands Test Facility            |
| Jerry Widmar            | NASA Johnson Space Center                 |
| Paul Wilde              | Federal Aviation Administration           |
| Rick Willardson         | Raytheon Intelligence & Space             |
| Robert Wingate*         | NASA Marshall Space Flight Center         |
| Michael Winter          | ETC Deutschland                           |
| Kamil Włodarczyk        | Northrop Grumman Innovation Systems       |
| Tommy Yoder             | NASA White Sands Test Facility            |

NOTE Names marked with an asterisk participated as Observer, nonvoting members.

The above consensus body approved this document on 16 September 2022.

The AIAA Standards Steering Committee (Paul Lambertson, Chair) accepted the document for publication on 6 December 2022.

The AIAA Standards Procedures dictates that all approved standards, recommended practices, and guides are advisory only. Their use by anyone engaged in industry or trade is entirely voluntary. There is no agreement to adhere to any AIAA standards publication and no commitment to conform to or be guided by standards reports. In formulating, revising, and approving standards publications, the committees on standards will not consider patents that may apply to the subject matter. Prospective users of the publications are responsible for protecting themselves against liability for infringement of patents or copyright, or both.

# 1 Scope

This Guide provides guidance for establishing baseline requirements for the design, analysis, manufacturing, test, and operation of composite overwrapped pressure vessels (COPV) with a plastic liner used for aerospace systems such as spacecraft and launch vehicles. This Guide is only applicable for a COPV with a plastic liner; the liner includes the metallic portions such as the bosses.

Requirements for COPVs levied from other authorities (such as Range Safety, FAA, DOT, etc.) may also be applicable. Specific applications, particularly those involving human spaceflight, may have additional requirements. There may also be additional requirements for hardware elements that are not addressed by this document, such as the presence of a propellant management device or diaphragm. The full set of these requirements may be identified before the design process begins and may be addressed through all stages of the lifecycle.

## 1.1 Purpose

This guidance for establishing requirements is intended to assure the safety and enhance the success of the operation of a COPV in an aerospace system.

## 1.2 Applicability

This Guide is applicable only to COPVs containing a plastic liner and constructed with a carbon fiber/polymer matrix overwrap. Applicable plastic liners are comprised of thermoset or thermoplastic polymer material and includes a metallic boss.

COPVs that include a fiberglass overwrap layer that serves only to protect the vessel from impact damage are permitted.

There are two companion standards to this Guide: ANSI/AIAA S-080A Space Systems—Metallic Pressure Vessels, Pressurized Structures, and Pressure Components and ANSI/AIAA S-081B-2018 Space Systems—Composite Overwrapped Pressure Vessels.

## 1.3 Designation of Responsibilities

This section identifies the responsibilities for the key agents: owner, procuring authority, and manufacturer.

It is noted that the owner and procuring authority may be the same entity.

The procuring authority and the manufacturer may also be the same entity, in which case additional consideration may be given regarding independent oversight.

### 1.3.1 Owner

The owner establishes the system level requirements. The owner develops the aerospace system incorporating the COPV to meet these system level requirements. The owner performs the system analysis on the aerospace system to identify the operational envelope, establishing the design requirements.

The owner is responsible for reviewing and approving any tailoring of requirements including the use of a document revision other than what is specified in Section 3.

The owner specifies options provided in the Guide before contracting with the manufacturer. For example, the burst factor (Section 5.2.1) and design safety factor (Section 5.2.4) are established. In addition, for the conditions established in Section 5.2.10, there may be options for the liner design and verification approach (Section 6.1).

The owner is responsible for recognizing the certification of trained COPV visual inspectors and the approval and implementation of the Inspection and Test Plan (ITP), including accept and reject criteria of necessary inspections and the creation and adherence to the Damage Control Plan (DCP).

The owner has the responsibility for approving engineering source approved (ESA) processes and subsequent changes. The owner may solicit engineering input prior to accepting ESA process changes.

The owner may delegate any of the above authority and decision-making responsibility to a procuring authority (typically an intermediate contractor or a consultant) but remains responsible for the overall system.

The owner may give special consideration before accepting (or allowing the procuring authority to accept) deviations from approved procedures and acceptance criteria.

Upon acceptance of the aerospace system, the owner is responsible for the operation of the COPV. The owner may operate the COPV in compliance with the Operations and Maintenance Requirements specified in Section 11.

The owner may approve all deviations from approved procedures and acceptance criteria set forth in this Guide.

### **1.3.2 Procuring Authority**

The procuring authority performs on behalf of the owner those responsibilities and authorities contractually agreed between the two parties.

Typically this includes delegated authority from the owner for development of an aerospace system incorporating the COPV, performance of the system analysis on the aerospace system to identify the operational envelope as specified in Section 5.1, and establishing the design requirements as specified in Section 5.2.

This Guide permits options for the COPV. With concurrence from the owner, the procuring authority may specify such options before contracting with the manufacturer. For example, the burst factor (Section 5.2.1) and design safety factor (Section 5.2.4) are established. In addition, for the conditions established in Section 5.1, there may be options for the liner design and verification approach (Section 6.1).

With concurrence from the owner, the procuring authority may have final responsibility for manufacturing and design decisions and may be required to review and approve all manufacturing and test procedures and results. This includes the preparation of coupons, samples, and/or test specimen COPVs that are representative of the flight COPV for damage tolerance life verification.

The procuring authority may give special consideration before accepting deviations from approved procedures and acceptance criteria.

### **1.3.3 Manufacturer**

The manufacturer is responsible for the overall design and fabrication of the COPV, including analysis and testing. This process involves procuring materials, constructing, testing, and certifying that the COPV is in compliance with the established requirements (in consideration of this Guide) as tailored by the owner and the procuring authority. The manufacturer is also responsible for developing the documentation required throughout the design and manufacturing of the COPV.

## **2 Tailoring**

The requirements identified in this Guide as referenced from the related standard (ANSI/AIAA S-081B-2018, as described in the Foreword) may be tailored to match the actual requirements of the particular program or project. Tailoring of requirements *\*may\** be undertaken in agreement with the owner and procuring authority (as appropriate).

**NOTE** Tailoring is a process by which individual requirements or specifications, standards, and related documents are evaluated and made applicable to a specific program or project by selection, and in some cases, modification, and

addition, or deletion of requirements in the standards. Such exceptions or modifications may be expressly delineated in applicable purchase orders, contracts, and other technical documents.

### 3 Applicable Documents

The following documents contain provisions which either through reference in the text constitute requirements of this Guide, or which provide useful background or guidance relevant to this Guide. For dated references, the specified edition applies. For undated references, the edition in effect at time of publication of this standard applies. The use of a revision other than that specified is permitted only after review and approval by the owner.

|                       |                                                                                                                                                      |
|-----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| AFFDL-TR-79-3021      | <i>USAF Damage Tolerance Design Handbook: Guidelines for the Analysis and Design of Damage Tolerant Aircraft Structures</i> , 1994                   |
| AFML-TR-68-115        | <i>Aerospace Structural Metals Handbook 38<sup>th</sup> edition</i> , 2004 or online <i>Aerospace Structural Metals Database</i> , CINDAS LLC, 2007  |
| AFSPCMAN 91-710 Vol 3 | <i>RANGE SAFETY USER REQUIREMENTS MANUAL VOLUME 3 – LAUNCH VEHICLES, PAYLOADS, AND GROUND SUPPORT SYSTEMS REQUIREMENTS</i> , 2019                    |
| AIA/NAS NAS 410       | <i>National Aerospace Standard Certification and Qualification of Nondestructive Test Personnel Rev. 4</i> , 2014                                    |
| ANSI/AIAA S-080A      | <i>Space Systems—Metallic Pressure Vessels, Pressurized Structures, and Pressure Components</i> , 2018                                               |
| ANSI/AIAA S-081B      | <i>Space Systems—Composite Overwrapped Pressure Vessels</i> , 2018                                                                                   |
| AS-9100               | <i>Quality Management Systems—Requirements for Aviation, Space and Defense Organizations</i> , 2009                                                  |
| ASNT SNT-TC-1A        | <i>ASNT Recommended Practice No. SNT-TC-1A: Personnel Qualification and Certification in Nondestructive Testing</i> , 2016                           |
| ASTM D150             | <i>Standard Test Methods for AC Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulation</i> , 2018.               |
| ASTM D638             | <i>Standard Test Method for Tensile Properties of Plastics</i> , 2014                                                                                |
| ASTM D648             | <i>Standard Test Method for Deflection Temperature of Plastics Under Flexural Load in the Edgewise Position</i> , 2018                               |
| ASTM D695             | <i>Standard Test Method for Compressive Properties of Rigid Plastics</i> , 2015 (This standard is equivalent to ISO 604.)                            |
| ASTM D696             | <i>Standard Test Method for Coefficient of Linear Thermal Expansion of Plastics Between –30°C and 30°C with a Vitreous Silica Dilatometer</i> , 2016 |
| ASTM D1434            | <i>Standard Test Method for Determining Gas Permeability Characteristics of Plastic Film and Sheeting</i> , 2015                                     |
| ASTM D1525            | <i>Standard Test Method for Vicat Softening Temperature of Plastics</i> , 2017                                                                       |

|                      |                                                                                                                                                                       |
|----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ASTM D3418           | <i>Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry</i> , 2015          |
| ASTM D3039/D3039M-08 | <i>Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials</i> , 2014                                                                       |
| ASTM D3163           | <i>Standard Test Method for Determining Strength of Adhesively Bonded Rigid Plastic Lap-Shear Joints in Shear by Tension Loading</i> , 2014                           |
| ASTM D5868           | <i>Standard Test Method for Lap Shear Adhesion for Fiber Reinforced Plastic (FRP) Bonding</i> , 2016                                                                  |
| ASTM D3418           | <i>Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry</i> , 2015          |
| ASTM D3985           | <i>Standard Test Method for Oxygen Gas Transmission Rate Through Plastic Film and Sheet Using a Coulometric Sensor</i> , 2017                                         |
| ASTM E740            | <i>Standard Practice for Fracture Testing with Surface-Crack Tension Specimens</i> , 2016 (2003 R16 EDITION)                                                          |
| ASTM E1004           | <i>Standard Test Method for Determining Electrical Conductivity Using the Electromagnetic (Eddy Current) Method</i> , 2017                                            |
| ASTM E1356           | <i>Standard Test Method for Assignment of the Glass Transition Temperatures by Differential Scanning Calorimetry</i> , 2014                                           |
| ASTM E2981           | <i>Standard Guide for Nondestructive Testing of the Composite Overwraps in Filament Wound Pressure Vessels Used in Aerospace Applications</i> , 2021                  |
| ASTM E2899           | <i>Standard Test Method for Measurement of Initiation Toughness in Surface Cracks Under Tension and Bending</i> , 2019                                                |
| ASTM E2982           | <i>Standard Guide for Nondestructive Examination of Thin-Walled Metallic Liners in Filament-Wound Pressure Vessels Used in Aerospace Applications</i> , 2021          |
| ASTM F3299           | <i>Standard Test Method for Water Vapor Transmission Rate Through Plastic Film and Sheet Using an Electrolytic Detection Sensor (Coulometric P2O5 Sensor)</i> , 2018. |
| ASTM MNL36-2ND       | <i>Use of Oxygen and Oxygen Systems: Handbook for Design, Operation, and Maintenance: Second ed.</i> , 2007                                                           |
| CMH-17               | <i>Composite Materials Handbook</i> , 2012                                                                                                                            |
| DOT/FAA/AR-MMPDS-10  | <i>Metallic Materials Properties Development Standardization (MMPDS)</i> , 2015                                                                                       |
| ISO 306              | <i>Plastics — Thermoplastic materials — Determination of Vicat softening temperature (VST)</i> , 2013.                                                                |
| ISO 9000             | <i>Quality management systems—Requirements</i> , 2015                                                                                                                 |
| ISO 9712             | <i>Non-destructive testing — Qualification and certification of NDT personnel</i> , 2005.                                                                             |

|                              |                                                                                                                 |
|------------------------------|-----------------------------------------------------------------------------------------------------------------|
| MIL-STD-464C                 | <i>Electromagnetic Environmental Effects, Requirements for Systems, 2010.</i>                                   |
| NASA ES4-09-031              | <i>NASA Carbon Overwrap Pressure Vessel Restrictions, 2009.</i>                                                 |
| NASA-SP-8007-2020/REV 2      | <i>Buckling of Thin-Walled Circular Cylinders, 2020.</i>                                                        |
| NASA-STD 6001B with change 1 | <i>Flammability, Offgassing, and Compatibility Requirements and Test Procedures, April 2016</i>                 |
| NASA/TM-2012-217371          | <i>Elements of Nondestructive Examination for the Visual Inspection of Composite Structures, September 2012</i> |
| SMC-S-016                    | <i>Test Requirements for Launch, Upper-Stage and Space Vehicles, 2014</i>                                       |

## 4 Vocabulary

### 4.1 Acronyms and Abbreviated Terms

|              |                                                    |
|--------------|----------------------------------------------------|
| <i>a</i>     | minor semi-axis of an elliptical flaw (crack)      |
| AFFDL        | Air Force Flight Dynamics Laboratory               |
| AFML         | Air Force Materials Laboratory                     |
| AIAA         | American Institute of Aeronautics and Astronautics |
| ANSI         | American National Standards Institute              |
| ASNT         | American Society for Nondestructive Testing        |
| <i>BF</i>    | burst factor                                       |
| <i>c</i>     | major semi-axis of an elliptical flaw (crack)      |
| C            | Celsius                                            |
| COPV         | composite overwrapped pressure vessel              |
| <i>da/dN</i> | fatigue crack growth rate in the “a” direction     |
| <i>dc/dN</i> | fatigue crack growth rate in the “c” direction     |
| DCP          | damage control plan                                |
| DOT          | Department of Transportation                       |
| DSC          | differential scanning calorimetry                  |
| ECF          | environmental correction factor                    |
| EPFM         | elastic/plastic fracture mechanics                 |
| ESA          | engineering source approved (as in ESA process)    |
| FAA          | Federal Aviation Administration                    |

|                 |                                                                                      |
|-----------------|--------------------------------------------------------------------------------------|
| FMEA            | failure modes and effects analysis                                                   |
| $F_{su}$        | shear ultimate strength                                                              |
| $F_{tu}$        | tensile ultimate strength                                                            |
| $F_{ty}$        | tensile yield strength                                                               |
| ITP             | inspection and test plan                                                             |
| $K$             | stress intensity factor                                                              |
| $K_c$           | plane stress fracture toughness                                                      |
| $K_{Ic}$        | plane strain fracture toughness                                                      |
| $K_{Ie}$        | surface or embedded crack fracture toughness                                         |
| $K_{IEAC}$      | stress intensity factor threshold for plane strain environmentally assisted cracking |
| $K_R$           | crack extension resistance                                                           |
| $\Delta K_{th}$ | cyclic threshold stress intensity range                                              |
| LBB             | leak before burst                                                                    |
| LEFM            | linear elastic fracture mechanics                                                    |
| MEOP            | maximum expected operating pressure                                                  |
| MEPD            | maximum external pressure differential                                               |
| MIL             | military                                                                             |
| MRB             | Material Review Board                                                                |
| $MS$            | margin of safety                                                                     |
| NASA            | National Aeronautics and Space Administration                                        |
| NDT             | nondestructive testing                                                               |
| POD             | probability of detection                                                             |
| QA              | quality assurance                                                                    |
| $\varepsilon-N$ | strain-life                                                                          |
| $S-N$           | stress-life                                                                          |
| STD             | standard                                                                             |
| $T_g$           | glass transition temperature                                                         |
| USAF            | United States Air Force                                                              |
| VT              | visual test                                                                          |

## 4.2 Terms and Definitions

For the purposes of this document, the following terms and definitions apply:

**A-basis allowable**

the lower of either a statistically calculated number or the specification minimum (S-basis). The statistically calculated number indicates that at least 99% of the population of values is expected to equal or exceed the specified values, with a confidence level of 95%.

**Acceptance tests**

the required tests conducted by the manufacturer on a flight item to ascertain that the materials, manufacturing processes, and workmanship meet specifications and that the item is acceptable for its intended use

**Allowable load**

the maximum load that can be accommodated by a structure (material) without rupture, collapse, or detrimental deformation in a given environment

NOTE Allowable loads commonly correspond to the statistically based minimum ultimate strength, buckling strength, and yield strength, as applicable.

**B-basis allowable**

the statistically calculated number above which at least 90% of the population of values is expected to fall, with a confidence level of 95%

**Burst factor**

a multiplying factor applied to the maximum expected operating pressure (MEOP) to obtain the design burst pressure

NOTE There is an environmental correction factor (ECF) to account for the difference between the conditions at which the burst test is performed and the worst-case environment as defined in Section 5.1.16.

**Composite overwrapped pressure vessel**

a pressure vessel with a composite shell fully or partially encapsulating a liner

NOTE 1 The liner serves as a fluid (gas or liquid) permeation barrier and may or may not carry substantial pressure loads. The composite shell generally carries a large portion of the pressure and environmental loads.

NOTE 2 This Guide is applicable only to COPVs with a plastic liner (and metallic boss) and a carbon fiber/polymer matrix overwrap.

**Critical damage**

damage that results in degraded strength of the COPV such that it can no longer meet the requirements of this Guide

**Critical process**

term usually used in industry to refer to a “special” manufacturing process. For polymer liners and composite overwraps, these processes can include, as examples, molding, fiber wrapping, application of resin to fibers, and adhesive bonding. For metallic liners, these processes can include, as examples, welding, heat treating, and brazing. A critical process can substantially affect material properties and may also be an engineering source approved process.

**Cyclic threshold stress intensity factor range**

the stress intensity factor range below which flaw growth will not occur under cyclic loading conditions

**Damage control plan**

a plan that identifies the damage threats to a COPV throughout the service life and documents the steps taken to reduce the possibility of damage due to these threats. The DCP also identifies the inspection points.

**Damage tolerance life**

the required period of time and number of cycles that the COPV liner can sustain in the expected service

environment.

Damage tolerance life for the metallic and non-metallic portions of the liner are addressed separately.

For the metallic portion of the liner, the damage tolerance life sets the number of cycles that the liner containing the largest undetected crack, flaw, or discontinuity, must survive without sustained load crack growth, detrimental deformation, leakage, or rupture.

For the non-metallic portion of the liner, the damage tolerance life sets the number of cycles that the liner containing the largest allowable surface crack, flaw, or interface defect, must survive without detrimental deformation, detrimental leakage, or rupture.

**NOTE** For purposes of damage tolerance life, the non-metallic portion of the liner includes the interface between the metallic and plastic portion of the liner.

**Defect**

one or more flaws whose aggregate size, shape, orientation, location, or properties do not meet specified acceptance criteria and are rejectable

**Design burst pressure**

the pressure that a COPV will sustain without rupture in the applicable operating environment

**Design safety factor**

a multiplying factor applied to the limit loads and/or maximum expected operating loads/stresses when evaluating adequacy of the structural design during the analytical assessment and/or test verification

**NOTE** The design safety factor is used to account for build-to-build hardware variability, uncertainty in internal load paths and stress/strain levels, and uncertainty in ultimate failure modes. It provides separation between the statistical distributions that describe loads and material properties.

**Detrimental deformation**

distortion, deflection, or displacement that prevents any portion of the COPV from performing its intended function or that reduces the probability of successful completion of the mission

**Development test**

a test that is conducted by the manufacturer in order to ascertain information used to check the validity of analytical techniques and assumed design parameters; to uncover unexpected system response characteristics; to evaluate design changes; to determine interface compatibility; to prove qualification and acceptance procedures and techniques; to establish accept/reject criteria for nondestructive tests (NDT); or any other purpose necessary to establish the validity of the design and manufacturing processes

**Embrittlement**

a process whereby exposure to service media or service conditions compromises a stressed material's mechanical performance. Various materials have different mechanisms of embrittlement, therefore it can manifest in a variety of ways, from slow crack growth to a reduction of ductility and toughness.

**Engineering source approved (ESA) process**

a manufacturing process that is placed under configuration management. Changes to this process would require appropriate written authorization.

**NOTE** Examples of ESA processes may include investment castings, unique or critical NDT techniques, and fiber surface treatments.

**Environmental correction factor (ECF)**

a multiplying factor applied to account for the change in material properties associated with the difference between the test temperature and the operating temperature

**NOTE** The ECF for the proof test and the ECF for the burst test may be different. If an ECF is considered invalid for a specific environmental condition, then the specific environmental condition may be applied to the test.

**Environments**

the environmental exposures (such as mounting, humidity, temperature, vibration, acoustic, shock, and radiation levels) that the COPV is subjected to after completion of manufacture and final inspection

**Fatigue**

the process of progressive localized permanent structural change occurring in a material subjected to fluctuating stresses and strains, and which may culminate in cracks or complete fracture after a sufficient number of cycles

**Fatigue life**

the number of cycles of applied external loads and/or pressurization that the unflawed pressurized item can sustain before a fatigue failure could occur

**Flaw**

a local imperfection or discontinuity in a structural material (examples include cracks, voids, delamination, etc.) that may be detectable by visual inspection or nondestructive testing and is not necessarily rejectable

**Flaw (crack) aspect ratio ( $a/2c$  or  $a/c$ )**

the aspect ratio of a surface flaw (crack) ( $a/2c$ ), a corner flaw (crack) ( $a/c$ ), or an embedded flaw (crack) ( $a/c$ ) in the liner where  $a$  is the minor semi-axis and  $c$  is the major semi-axis of the flaw (crack)

**Flow stress**

the average of the yield and ultimate stresses

**Fracture control**

the application of design philosophy, analysis method, manufacturing technology, quality assurance, and operating procedures to prevent premature structural failure due to the propagation of cracks or crack-like flaws during fabrication, testing, transportation and handling, and service

**Glass transition temperature ( $T_g$ )**

the approximate midpoint of the temperature range over which the glass transition takes place

NOTE The glass transition temperature can vary significantly depending on the specific property chosen for observation and on details of the experimental technique.

**Hazard**

a real or potential condition that can lead to an unplanned event or series of events (i.e., mishap) resulting in loss of personnel capability, injury, illness, or death to personnel or the public, damage to or loss of system, equipment, or property, or damage to the environment

**Hazard analysis**

the determination of hazards and recommended resolutions for those conditions which may cause loss of personnel capability, injury, illness, or death to personnel or the public, damage to or loss of system, equipment, or property, or damage to the environment. The hazard analysis includes assessment, causes, controls and proven mitigations.

**Hazardous application**

an application in which a hazard exists (i.e., a potential risk situation that may be caused by an unsafe act or condition, such as the presence of a hazardous fluid) with the exception of the explosive energy resulting from the pressure of the contained fluid(s)

**Hazardous fluid**

a fluid that presents a hazard

NOTE 1 Examples include fluids with high toxicity, flammability, explosivity, and corrosivity.

NOTE 2 Asphyxiation is exempted for non-crewed applications.

**Hydrogen embrittlement**