# Procedures and Guidelines (PG)

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| **DIRECTIVE NO.** | 500-PG-8700.2.4F | **APPROVED BY Signature:** | ***Original signed by:*** |
| **EFFECTIVE DATE:** | 11/09/2015 | **NAME:** | Felicia Jones-Selden |
| **EXPIRATION DATE:** | 11/09/2020 | **TITLE:** | Director for AETD |

**COMPLIANCE IS MANDATORY**

**Responsible Office:** 500/Applied Engineering and Technology Directorate

**Title:** Mechanical Design and Development

## PREFACE

### P.1 PURPOSE

This PG establishes guidelines and requirements for AETD Product Design Team (PDT) members providing mechanical design and development support to GSFC products covered by the scope of the GSFC Management System.

### P.2 APPLICABILITY

This PG is applicable to AETD Product Design Team (PDT) members developing in scope Management System space flight mechanical products.

### P.3 AUTHORITY

GPR 1280.1, The GSFC Quality Manual
GPR 8700.1, Design Planning and Interface Management
GPR 8700.2, Design Development

### P.4 REFERENCES

1. GSFC-STD-1000, Design, Development, Verification, and Operation of Flight Systems (Gold Rules)
2. GSFC-STD-7000, GENERAL ENVIRONMENTAL VERIFICATION STANDARD (GEVS) For GSFC Flight Programs and Projects
3. GPR 1410.2, Configuration Management
4. GPR 5330.1, Work Order Authorization (WOA) Process
5. GPR 5340.2, Control of Nonconformances and Customer Complaints
6. GPR 8700.1, Design Planning and Interface Management
7. GPR 8700.2, Design Development
8. GPR 8700.3, Design Validation
9. GPR 8700.4, Goddard Systems Reviews
10. GPR 8700.6, Engineering Peer Reviews

11. 500-PG-8700.2.5, GSFC Engineering Drawing Requirements Manual
12. 500-PG-8700.2.9, Issue and Management of GSFC Engineering Drawing Numbers
13. 540-PG-8700.2.3, Computer Aided Design Guidelines and Requirements for Flight Projects
14. 547-PG-8072.1.1, Manufacturing Process

## P.5 CANCELLATION

500-PG-8700.2.4E, Mechanical Design and Development Guidelines

## P.6 SAFETY

NONE

## P.7 TRAINING

NONE

## P.8 RECORDS

No unique records are generated as a result of this PG.

| Record Title | Record Custodian | Retention |
|---|---|---|
| N/A | | * |
| | | * |

** NRRS 1441.1 – NASA Records Retention Schedule*

## P.9 MEASUREMENT/VERIFICATION

None.

## PROCEDURES

In this document, a requirement is identified by "shall," a good practice by "should," permission by "may" or "can," expectation by "will" and descriptive material by "is."

The PDL (Product Design Lead, hereafter referred to as the lead engineer) shall be responsible for the quality and timely completion of the mechanical design and development activities as per the project's requirements,and Statements of Work (SOW).

The PDL shall provide the design output (documentation including engineering drawings, test plans, procedures, and reports), budgets, schedules, and review support to the customer (typically a project or instrument manager). It is the responsibility of the lead engineer, in partnership with the customer, to

determine and document in a design plan (per GPR 8700.1, Design Planning and Interface Management) which specific steps of the typical mechanical design and development process (as described herein) will be executed.

The following procedure describes a typical process for providing mechanical design and development support to a customer. Again, for the purposes of this document, "customer" would typically refer to a project or instrument manager. The actual design and development process is by nature iterative and must maintain some degree of flexibility.

1. Compilation of Design Inputs

The lead engineer compiles and evaluates the Design Inputs which may include one or more of the following:

- Statement of Work
- Customer imposed requirements
- Interface Control Drawings (ICDs)
- Applicable NASA directives, internal requirements, specifications, standards, and statutory/regulatory requirements
- Applied Engineering and Technology Directorate (AETD) imposed requirements

2. Initial Planning

2.1. The lead engineer develops the Design Plan, which contains a high level description of the mechanical hardware to be developed, key support personnel, a budget, and a schedule for review and approval by the customer. The plan should include adequate contingencies for completion of the design and development activity within the resources negotiated in the budget, schedule, and/or SOW. This plan should also include a "basis of estimate (BOE)." A project or instrument manager may request this design plan information be documented in a formal Subsystem Implementation Plan (SIP) for the mechanical subsystem. Other approaches may be to have the design planning documentation combined with other discipline inputs and consolidated into a Project Plan, or the design planning documentation may be a part of several individual project documents. Regardless of the approach, the design planning documentation is a record and shall be maintained per the applicable configuration management plan for this design and development activity.

2.2. The lead engineer, with assistance from line management, should ensure that the PDT is composed of individuals, civil servants and/or contractors as necessary, with the required discipline skills.

3. Requirements Definition

The lead engineer supports the generation of mechanical requirements from the top-level requirements and/or design inputs. It may be necessary for the PDT to perform various analyses in order to derive

lower level design requirements from the top-level requirements/design inputs. These top level and derived requirements should be documented, reviewed for adequacy and consistency with relevant NASA and GSFC directives and internal requirement documents, and signed off by the lead engineer and the customer. The requirements documents are to be maintained per the applicable configuration management plan, per GPR 1410.2, Configuration Management.

4. Design Practice

The design effort is conducted according to GPR 8700.2, Design Development, and according to the following good design practices, as appropriate:

4.1. Multiple design concepts should be identified, and the best selected by a trade study process. The best design concept is that which fully meets all of the design requirements and considers cost, technical complexity, schedule risk, technology infusion, design heritage, and other factors as appropriate. It may be necessary to prototype one or more of the design options and to conduct various performance and/or environmental tests before the optimum design path is chosen. In any case, the customer should be a key participant in this critical selection process. In addition, the results of the trade study process are typically "peer reviewed." (See GPR 8700.6, Engineering Peer Reviews)

4.2. The lead engineer should query the NASA Engineering Network Lessons Learned (ENLL) site (https://nea.nasa.gov/web/ll/). The ENLL is an on-line, automated database system designed to collect and make available for use the NASA lessons learned from many years in the aeronautics and space business. The ENLL enables the knowledge gained from past experience to be applied to current and future projects. Its intent is to avoid the repetition of past failures and mishaps, as well as the ability to share observations and best practices. Through this resource, the lead engineer may facilitate the early incorporation of safety, reliability, maintainability, and quality into the design of flight and ground support hardware, software, facilities, and procedures.

4.3. Designs are developed in accordance with the fundamental design principles and requirements described in the Design, Development, Verification, and Operation of Flight Systems (GSFC-STD-1000), also known as the Gold Rules. Any deviations are approved by project waiver or exception.

4.4. Detailed designs should be as simple as possible, making maximum use of standardization, repeated elements, known processes, and readily available parts and space qualified materials.

4.5. Designs should be robust, insensitive to fabrication tolerances, and consider ease of assembly. Tolerances specified on drawings should be achievable and only what is needed for proper operation/function. Excessively tight tolerances result in higher costs to manufacture, potentially more rejected parts, and usually longer lead times before delivery.

4.6. All appropriate functional discipline personnel (e.g., manufacturing, materials, assembly, testing, thermal, electrical, etc.) who are involved in or associated with the system or item being designed, should be included in the PDT, or, as a minimum, be consulted to review the design and make suggestions to improve manufacturability and/or reduce the manufacturing costs and improve assembly and/or testability. The lead engineer should decide whether to accept or reject these recommendations.

4.7. The lead engineer should establish the Computer-Aided Design (CAD) software to be used for designing flight hardware and critical MGSE. The CAD software should be interfaced with data management software (Windchill PTC Product Lifecycle Management or equivalent) in order be accessible by multiple users simultaneously in a shared data environment, and to manage CAD data in combination with the project's configuration management database. Further CAD requirements and guidelines for the Mechanical Systems Division are found in 540-PG-8700.2.3, Computer Aided Design Requirements and Guidelines for Flight Projects.

4.8. Fabrication drawings of flight hardware and qualification hardware and ground support equipment hardware that interface with flight hardware (Critical GSE) are produced in accordance with 500-PG-8700.2.5, GSFC Engineering Drawing Requirements Manual. Some or all of these drawing practices may also be applicable to pre-flight and pre-operational hardware (such as engineering test units, breadboards, and proof-of-concept hardware), but are not required. Applicability should be determined by the lead engineer. Fabrication drawings should be complete and unambiguous, containing all the necessary information to produce the desired part. Instructions for obtaining official GSFC Drawing Numbers are found in 500-PG-8700.2.9, Issue and Management of GSFC Engineering Drawing Numbers.

4.9. The lead engineer shall be responsible for assuring that all fabrication drawings of flight and qualification hardware and Critical GSE are checked for accuracy and completeness and are approved. For multiple part assemblies, assembly drawings, detailed layout drawings, 3-D models, or some other means to convey how the piece parts fit together should be provided so that tolerance studies can be conducted to assure proper fit.

The following short checklists of Mechanical Design Considerations and commonly used Mechanical Design References are provided as an aid in implementing the design.

4.9.1 Mechanical Design Considerations:

- Materials selection (space flight qualified, ferrous/non-ferrous, composite, ceramic, etc.)
- Environmental effects (static and dynamic loads, temperature, humidity, radiation, etc.)
- Analyses required (structural, thermal, optical, or various combinations of these analyses, torque margin, fracture, fatigue, vibroacoustic, transportation, venting, pressure, etc.)
- Ground support equipment (GSE) and logistics (handling, shipping, maintenance, storage)
- Ease of manufacture and assembly
- Testability
- Contamination control

- Fracture control
- Electrostatic Discharge (ESD) sensitivity/grounding

4.9.2 Mechanical Design References:

The following websites provide many commonly used design references such as NASA Handbooks and Standards, drawing standards, materials standards, range safety documents, safety documents and more.

- https://mscweb.gsfc.nasa.gov/543web/designref.html
- https://spaces.gsfc.nasa.gov/display/CODE543/Home

5. Design Changes

Design changes, as required by customer request, process improvement, errors in the original design, improper component selection, drawing error, product non-conformance, etc., are to be documented, approved, and implemented per the relevant configuration management plan (GPR 1410.2, Configuration Management).

6. Design Reviews

At appropriate stages throughout the mechanical design and development process, reviews shall be scheduled and conducted.

6.1. Internal or Table Top reviews are held during the design process and are truly at the grass roots level. Participants of these informal reviews are usually members of the PDT and other mechanical engineers/technicians. Though not required, informal documentation and tracking of action items sometimes occurs at the discretion of the lead engineer.

6.2. Engineering Peer Reviews (See GPR 8700.6, Engineering Peer Reviews) are more formal reviews that evaluate a design's technical status using a team of appropriate specialists independent from the PDT. They are conducted as specified in the Engineering Peer Review Plan (See GPR 8700.6). Emphasis should be placed on selecting a well-rounded review team consisting of personnel cognizant of and experienced with the subject matter of the review. These reviews are conducted to ensure that the mechanical design fully meets the design requirements. It is the responsibility of the lead engineer and/or PDT to respond to all Requests for Action (RFA's) generated at the reviews. Engineering Peer Reviews can be scheduled at any time during the design and development process. Some typical reasons for scheduling an Engineering Peer Review could be any one or more of the following:

- Required per the Engineering Peer Review Plan (See GPR 8700.6)
- Review a new design
- Review results of trade study
- Review modifications to an existing design or to existing design requirements

- Preparation for an Integrated Independent Review
- Preparation for a complex functional or environmental test
- Preparation for a complex shipment of hardware

6.3. Goddard Systems Reviews (See GPR 8700.4, Goddard Systems Reviews) provide expert technical review of the end-to-end mission system and are conducted at the system-level at critical milestones in project formulation and implementation. They are conducted as specified in the project's Goddard Systems Review Plan (See GPR 8700.4). The Goddard Systems Review Team consists of a chairperson and a team of technical and systems management experts independent of the program and project team. The status of the mechanical design and development is presented at these reviews by the mechanical lead engineer/PDT. Other lead engineers/PDTs present the status of their respective subsystems at these reviews. These reviews are conducted to ensure that the system design fully meets the design requirements. Again, it is the responsibility of the lead engineer and/or PDT to respond to all Requests for Action (RFA's) generated at the reviews for their respective subsystem. Reviews typically conducted include a Requirements Review, Systems Concept Review, Preliminary Design Review, Critical Design Review, Pre-Environmental Test Review, and a Pre-Ship Review.

7. Design Verification

During the engineering design and development process, design verifications are conducted to ensure that the design meets all of the customer's requirements, as well as all derived requirements. Verification testing and analysis is done in accordance with GSFC-STD-7000, GENERAL ENVIRONMENTAL VERIFICATION STANDARD (GEVS) For GSFC Flight Programs and Projects.

7.1. The following analyses should be performed and documented as appropriate:

- Structural Analysis
- Torque Margin Analysis
- Field of View Analysis
- Thermal Analysis
- Dynamic Simulation
- Various other methods of calculation/analysis, such as combined structural, thermal and optical analyses, stray light analyses, etc.
- Review and comparison to similar systems/designs

7.2. Engineering Peer and Goddard Systems reviews are conducted as described in Section 6 of this procedure to verify that the design and test documentation meets all customer requirements.

7.3. Development and testing of the flight hardware, as well as proof-of-concept designs, engineering or qualification test units, and life test units may be conducted as part of the design verification.

7.4. The Work Order Authorization (WOA) is utilized (per GPR 5330.1, Work Order Authorization (WOA) Process) to plan and document the processing of a product as it progresses from the initial stages of manufacture through integration, inspection, and test events, including all functional and environmental tests, required for design verification.

8. Design Validation

The lead engineer/PDT validates the product in accordance with GPR 8700.3, Design Validation. Validation of the design is done to ensure that the product accomplishes its intended purpose. This can be done at various phases of the product processing including manufacturing, integration to larger systems/assemblies, as well as by conducting environmental and functional tests. Validation testing is done in accordance with GSFC-STD-7000, GENERAL ENVIRONMENTAL VERIFICATION STANDARD (GEVS) For GSFC Flight Programs and Projects.

8.1. The lead engineer should determine the most appropriate and efficient method for fabrication of the hardware. Options include the Advanced Manufacturing Branch, which provides a full complement of planning, contracting, and monitoring services (See 547-PG-8072.1.1, Manufacturing Process, for more detailed information), task order contracts, or any other contracting medium that accesses a viable fabrication resource. Please note that fabrication and assembly tasks processed through the Advanced Manufacturing Branch use an electronic database system as described in 547-PG-8072.1.1, Manufacturing Process. Requests to initiate the fabrication effort do not require a WOA.

8.2. All flight hardware, qualification hardware, and Critical GSE shall have critical dimensions, as a minimum, inspected. The lead engineer should be responsible for identifying the critical dimensions and for the disposition of any discrepancies. Discrepant parts may be dispositional as “rework, repair, use-as-is, reclassify, return to vendor, or scrap.” See GPR 5340.2, Control of Nonconformances and Customer Complaints, for more detailed information.

8.3. Assembly and integration of flight hardware should be performed in accordance with an assembly drawing and/or plan. Assembly, integration, inspection, and test events shall be documented via the Work Order Authorization process defined in GPR 5330.1, Product Processing, Inspection and Test. All assembly and integration activities should be performed with the appropriate safety considerations addressed for personnel and/or hardware, and under the appropriate environmental conditions. Some items for consideration are:

- Cleanliness requirements
- Temperature/humidity requirements
- Crane access
- Adequate space
- Unique power and/or grounding requirements
- Alignment operations requiring specialized GSE
- Special tooling/fixtures
- Safety considerations

8.4. Validation Testing should be conducted using approved (formally released) test plans and procedures. The following extensive list of validation (and verification) tests, the majority of which have significant mechanical design implications, should be considered and conducted as appropriate:

- Interface testing (mechanical and electrical)
- Functional testing
- Deployment testing
- Life testing
- Mass Properties testing
- Spin Balance testing
- Strength testing (static pull, sine burst, or centrifuge testing)
- Vibration testing (random and/or sine sweep)
- Shock testing
- Acoustics testing
- Modal testing
- Thermal Vacuum testing
- Thermal Balance testing
- EMI/EMC testing
- Magnetic testing

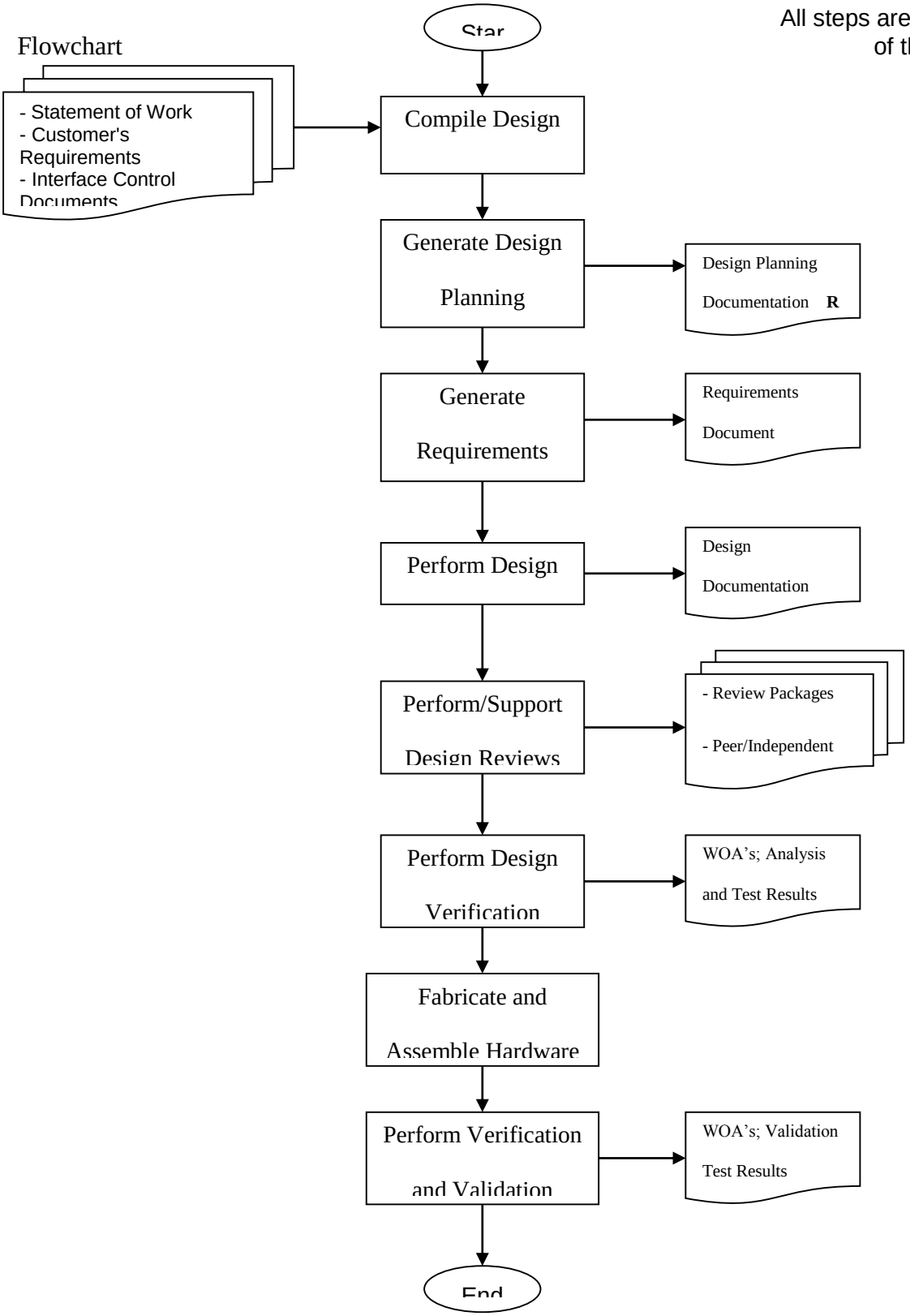
8.5. All tests should be analyzed and evaluated to ensure that all customer requirements have been validated. Anomalies found during the validation process are documented and resolved per GPR 5340.2, Control of Nonconformances and GPR 1710.1, Corrective and Preventive Action.

9. Communicate Design Output

The lead engineer/PDT should assure that both the design output (e.g., engineering drawings, electronic models, test plans, procedures, reports, review documentation) and the design progress (technical, budget, schedule) are communicated to the appropriate configuration management system per GPR 1410.2, Configuration Management and to the customer upon request.

Flowchart

All steps are the responsibility of the Lead Engineer and/or PDT.
**R**=Record



## Appendix A – Definitions

A.1 **Critical GSE** - Mechanical or electrical Ground Support Equipment (developed or procured) used in support of product development that is in direct contact with or in close proximity to the product and having properties such that inadequate design or manufacture, malfunction, improper function, or failure of which could cause personnel injury or product damage.

A.2 **Customer** - Any organization or person receiving mechanical design and development support from the AETD.

A.3 **Design Plan** - The documentation created as a result of executing GPR 8700.1, Design Planning and Interface Management. This documentation consists of schedules and budgets, a work breakdown structure, a verification and validation plan and other information. It may be gathered together as a single document, consist of multiple documents, or be a portion of a more comprehensive document, such as a Project Plan, Implementation Plan, or equivalent.

A.4 **Interface Control Document** – A specification of the mechanical, thermal, electrical, power, command, data, and other interfaces that system elements must meet.

A.5 **Product Design Lead (PDL)** - The PDL is the manager or leader that is responsible for managing the design activity, managing the technical and organizational interfaces identified during design planning, and where required, forming and leading the Product Design Team (PDT). The term PDL may refer to flight project managers, mission managers, instrument managers, subsystem technical managers, integrated product development team leaders, lead engineers, or others who have the responsibility for managing a design activity.

A.6 **Product Manager** - The manager or leader responsible for a product.

A.7 **Validation** - Proof that the product accomplishes the intended purpose. May be determined by test, analysis, and demonstration.

A.8 **Verification** – Proof that the design is compliant with requirements and specifications. May be determined by test, analysis, inspection, and similarity.

## Appendix B – Acronyms

| | |
|---|---|
| AETD | Applied Engineering Technical Directorate |
| CAD | Computer Aided Design |
| CM | Configuration Management |
| EMC | Electromagnetic Compatibility |
| EMI | Electromagnetic Interference |
| ENLL | Engineering Network Lessons Learned |
| EPR | Engineering Peer Review |
| ESD | Electrostatic Discharge |
| FRC | Federal Records Center |
| GPR | Goddard Procedural Requirements |
| GSE | Ground Support Equipment |
| GSFC | Goddard Space Flight Center |
| ICD | Interface Control Document |
| IIRT | Integrated Independent Review Team |
| NARA | National Archives and Records Administration |
| NRRS | NASA Records Retention Schedule |
| PDL | Product Design Lead |
| PDT | Product Design Team |
| RFA | Request for Action |
| SOW | Statement of Work |
| WOA | Work Order Authorization |

| Revision | Effective Date | Description of Changes |
|---|---|---|
| Baseline | 01/14/99 | Initial Release |
| A | 06/10/99 | Modified format to conform to GPG 1410.1A. Corrected incorrect document number references (500-PG-1310.1.1). Listed references in numerical order. Clarified quality records requirements in text and flowchart. Clarified WOA usage requirements for verification and validation. Introduced the Work Request form used in the Fabrication Management Process. Clarified drawing standards requirements for engineering test units versus flight units. |
| B | 08/17/1999 | Added Design Plan definition from GPG 8700.1. In 8.2.1, provided several approaches for documenting design plan information. Added GPG references to Quality Record Title. Under Implementation, added clarifying words for "customer" as used in the context of this document. |
| C | 03/24/2004 | Modified format to conform to GPG 1410.1D. Corrected Records Section P.8 to reflect the correct Record Title and Custodian. Corrected multiple reference documents throughout this PG to reflect current titles and/or document numbers. Added Section 4.2. Clarified Integrated Independent Reviews (see section 6.3). |
| D | 07/29/2005 | Updated References from GPGs to GPRs and corrected some titles. Reworded requirements with "shall" statements throughout document. Changed "quality records" to "records" throughout document. Added GSFC-STD-1000 to Section 4.8.2. |
| E | 09/03/2010 | Modified format to conform to new PG Template including adding acronym list as Appendix B. Changed title of document by removing "Guidelines." P1. & P2. Deleted "Quality" from Quality Management System. P4. Updated References 4.7 Updated details to locate engineering drawing numbers. Removed numerous document titles and replaced with website to locate these documents. Minor edits throughout. |
| F | 11/09/2015 | Reduced many "shall" statements where unnecessary. P1-P4. Updated References. Added 4.7 CAD section. Minor edits throughout. |