



ENGINEERING AND MANUFACTURING
PRACTICES FOR DEFECT
PREVENTION:
A Guide For Aerospace
Acquisition Management Teams

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1. BACKGROUND

Basic quality systems have traditionally focused on the identification and control of hardware that fails to meet specified requirements. A basic quality system functions properly when it precludes nonconforming hardware from getting into the hands of the customer. Nonconforming material is usually identified through extensive inspection and testing. Once identified, the hardware is segregated and dispositioned through the preliminary review or material review board process, in which a determination is made whether the hardware should be used as is, reworked or repaired, or scrapped.

Although preventing nonconforming material from reaching the hands of the customer is a critically important function, the basic quality assurance approach suffers from a number of drawbacks. Foremost among these drawbacks is that the identification and correction of defects have proved to be much more costly than preventing their occurrence in the first place. Such activities as inspection, test, segregation and processing of nonconformances, and rework each incur costs and yet add no value to the product. Secondly, inspection and test -- even when performed on a 100% basis -- often fail to identify all existing nonconformances. One hundred percent inspection has proved to be less than 100% effective in identifying defects. Lastly, the use of inspection and test as the principal means of determining product acceptability has frequently led to the perception that workers who perform such inspections and tests -- rather than those who design, fabricate and assemble the product -- are responsible for product quality.

To overcome these drawbacks and help prevent unnecessary costs, product quality should be achieved by emphasizing the prevention of defects rather than after-the-fact detection of defects. Such an approach involves structuring a development process to achieve producible designs and capable, controlled manufacturing processes. An integrated multi-functional approach to achieving and maintaining quality throughout the product development and production decreases cycle time and reduces rework, engineering changes, and inspections and tests. These benefits translate into improved affordability and reduced production transition risk.

2. PURPOSE

The ANSI/ASQC Q9000 series, or equivalent, forms the basic minimum quality system models for buying activities. The Q9000 series was written to provide the latitude of implementing either a defect detection or a defect prevention approach. The Joint Aeronautical Commanders Group (JACG) has prepared the guidance contained herein to assist in implementing a defect prevention approach.

Users of this document should note that the guidance contained herein departs from the traditional approach for communicating expectations to potential suppliers -- i.e., including a lengthy set of detailed model contract requirements in the procurement instrument. Experience has shown that award of new business is far more effective than simple contract requirements in motivating companies to change. The JACG intends for the guidance in this document to be used to (1) encourage offerors to describe in their proposals their approaches for moving beyond simple defect identification and correction quality systems to defect prevention; (2) identify and select offerors who

propose credible approaches and processes to reduce risk and produce a quality product at an affordable price; and (3) incorporate, where appropriate, the salient elements of the offeror's approach into the final contract.

It is important to note that defect prevention practices become the responsibility of every member of the integrated product team! No longer can the inspectors and testers from the days of defect identification and correction be left alone to face criticisms of poor product quality.

3. CONTENTS

Section 4 describes and explains why the transition from defect identification and correction to defect prevention is important. Section 4 also describes various process attributes, tools, and business practices to achieve product quality. Product quality is herein defined as meeting the customer requirements at an affordable cost.

4. DISCUSSION

This section is intended to assist the reader in understanding why defect prevention practices are important from the standpoint of affordability and in mitigating the risks of transitioning to production. It serves as a primer by introducing and summarizing some of the process attributes, tools, and business practices that may be applied to complex aerospace acquisition programs. Given that equipment acquired by aerospace community buying activities includes everything from satellites and manned and unmanned vehicles to engines, avionics and ground support equipment, it should be obvious that there is no "one-size-fits-all" approach to defect prevention. In addition, the summaries of tools, attributes and business practices contained herein do not provide sufficient detail to be the sole reference source for the uninformed reader. Users of this guide are strongly urged to gain a detailed understanding of these topics, as well as other related engineering and management practices and philosophies, prior to applying any of the principles contained herein.

4.1 SCOPE OF THIS GUIDE

Aerospace community acquisition management teams can consult this guide in the planning process for nearly any development or production contract. The guide's applicability, however, may vary depending on the program and acquisition process (particularly for acquisitions of Non-Developmental Items, Commercial Off-the-Shelf systems, purely build-to-print acquisitions such as procurements of spares and repair parts, and programs where only software or services (such as maintenance) are being procured).

4.2 DEFECT PREVENTION - A DESCRIPTION

A defect prevention approach emphasizes matching the design requirements to the process limitations and then controlling the process to facilitate the production of conforming product. The additional confidence in design and production planning reduces development phase uncertainty in cost estimating and in cost-containment efforts, decreasing overall program risks. It is therefore increasingly relevant to consider defect prevention approaches proposed by offerors as important discriminators in source selection.

Reduced costs and risk can be achieved through explicitly influencing the design process with producibility and manufacturing considerations. Doing so improves product quality and manufacturing efficiency by enhancing the predictability of manufacturing operations, reducing waste in material and labor, decreasing production cycle time, reducing the need for engineering changes, and minimizing the required overhead and sustaining engineering.

4.2.1 Integrated Product and Process Development (IPPD) Framework

Since defect prevention encompasses both design and manufacturing, it is initially applied during the development phase, normally within an integrated product and process development framework. IPPD focuses on achieving robust, producible and supportable designs.. Within this framework, producibility objectives are achieved in a systems engineering environment utilizing a thorough knowledge of manufacturing process risks. While this early emphasis on the optimization of the design/manufacturing process interface may necessitate the application of additional resources in the development phases, the potential benefits (including decreased engineering changes, production cycle time, rework, and inspections) translate into improved life cycle affordability and reduced production transition risk.

IPPD requires the involvement of personnel from a number of functional disciplines (e.g., design, manufacturing engineering, production operations, quality, tooling design and fabrication, industrial engineering), including appropriate subcontractor personnel, in the design process. In an IPPD approach, design trade studies will explicitly consider manufacturing factors (e.g., manufacturing technology, tooling, fabrication and assembly costs, sources of supply, tolerances, part count, yields and verification methods) to ensure that fully informed decisions affecting these factors are made before significant resources are committed.

There are many tools for facilitating IPPD. As an example, quality function deployment (QFD) provides a structured, team-oriented planning methodology for translating the top-level customer needs into appropriate requirements at each level of product and process design. The proper application of QFD has been proven to (1) reduce overall development time, (2) reduce the number of changes required after production start, and (3) improve customer response to new products. A subset of tools for IPPD, focusing on defect prevention, are given below.

4.2.2 Tools and Attributes

4.2.2.1 Identification and Control of Key Product Characteristics

Key product characteristics are the features of a material or part whose variation has a significant influence on product fit, performance, service life, or manufacturability. The designation of key product characteristics is a valuable method for design engineers to communicate to manufacturing personnel the specific features of the design that are most important for the factory to control during manufacture and test. The designation of key product characteristics also indicates to other engineers those product features that need special care when design changes are being made and can be used by

manufacturing personnel to identify design features that factory data indicate are problematic. In any case, the principal benefit of identifying key product characteristics is that doing so highlights those manufacturing processes -- out of the thousands that can exist in a large factory -- which should be the focus of process control and variability reduction efforts.

World class manufacturers identify each part's key product characteristics on the part's drawing and on affected assembly drawings, work instructions and process specifications. Because the continuous reduction in part-to-part variation in these key product characteristics is of primary importance, statistical process control techniques are used for controlling key product characteristics in production.

A key characteristic must be measurable using either variable (i.e., discrete dimensions) or attribute (i.e., go/no-go) data. Key product characteristics should be defined in terms of impact upon both the external and internal customers. If, for example, a characteristic results in a high internal rejection rate for the manufacturer, that characteristic should probably be considered key. Viewed from the ultimate (external) customer's perspective, such a characteristic may not appear important; however, it is important from the internal customer's perspective because it results in rework, scrap and lost dollars.

A number of methodologies exist to facilitate the identification of key product characteristics, including analysis of historical data, Failure Modes and Effects Criticality Analysis (FMECA), and Fault Tree Analysis (the latter two methods should be applied to identification of characteristics/parameters associated with both the product and process design). QFD (see above under IPPD discussion) and design of experiments can also be employed to assist in the identification of key product characteristics.

Key process parameters derive directly from the key product characteristics. As manufacturing processes are designed in conjunction with design of the product, the processes that produce the key product characteristics are identified. The individual key process parameters are then identified using QFD or a similar approach so that appropriate controls and variability reduction practices (see below) can be developed and employed to ensure the final key product characteristics will conform. Once these key product characteristics and associated key process parameters are identified, process capability studies are used to verify that they can be achieved with the planned tooling and processes, or the parts or processes are redesigned as required.

Note: It is important for the purposes of this guide to distinguish between "key product characteristics" and "key processes" as defined herein and the commonly used term "critical characteristic". In general, key product characteristics and key processes are associated directly with product fit, performance, service life, or manufacturability, whereas critical characteristics focus on personnel safety and mission performance. A critical characteristic is any feature of an end item, subassembly, material, or process for which a resulting nonconformance is likely to result in a hazardous or unsafe condition for individuals using, maintaining, or depending on same. Nonconformance in a critical characteristic can also be considered likely to prevent performance of the tactical function of a major end item such as an aircraft or weapon system.

4.2.2.2 Design to Manufacturing Process Capability

All manufacturing processes exhibit variability. For processes in a state of statistical control, this variability can generally be characterized as a normal distribution (measured in standard deviations or “sigma”) about a mean value. Design tolerances are established so that manufacturing process variability falls within these limits. This relationship is measured by process capability indices (Cp, Cpk). Commonly, the manufacturing processes that control key product characteristics must achieve a certain minimum process capability index value. (This value typically ranges from a Cpk of 1.33 for non-complex mechanical parts to 2.00 for parts used in complex commercial electronic systems that must exhibit extremely high reliability.)

In order to design a product to the capability of the manufacturing process that will produce it, it is imperative that that capability be understood. Depending on whether the manufacturing process is presently in use or must be developed, the process capability analysis will require using either existing historical data, designed experiments, or some method of modeling or estimating process capability. What needs to be determined is the natural variability of the process when in control (stable). Basic statistical techniques can be employed in this analysis, including tests for normality, to characterize the process and determine whether it is, in fact, under control. If not, causes of special variation are identified and eliminated.

World-class manufacturers use their knowledge of process capabilities to analyze tolerance stacking in every assembly interface area. By assessing the capability of each fabrication process and of assembly tooling, and by understanding the statistical tolerance range of each part type, the impact of worst case tolerance stackups can be assessed. Doing so allows an early influence on the design of parts, processes, and tooling that can preclude unacceptable tolerance stackups.

Prior to the initiation of production, world-class manufacturers validate and verify (i.e., “proof”) that all key processes demonstrate sufficient process capability to ensure that the key product characteristics for parts resulting from the process will be within the design tolerance. Validation and verification is performed in a production-representative environment, including production workers, tools, space, materials, documentation, etc. and is scheduled so that required corrective actions (such as process or tooling changes) can be accommodated, if test results dictate, in time to affect the fabrication and assembly of the first production articles.

4.2.2.3 Design for Assembly/Manufacturing (DFA/M)

DFA/M techniques enable the reduction of product cost through design simplification. DFA/M achieves such simplification through parts reduction and by ensuring that the remaining parts are easy to manufacture and assemble. DFA/M usually results in significantly enhanced product quality because many nonconformances are attributable to product complexity. Defects such as missing or loose fasteners, faulty connections, and incorrectly installed parts all tend to be a function of product complexity. For each fastener or connector eliminated from the design, for example, the opportunity for one of these types of defects to occur is also eliminated. (Source: “Product Design for Assembly,” Boothroyd Dewhurst, Inc., 1991)

4.2.2.4 “Robust” Design

A “robust” design results in a product that is insensitive to or tolerant of sources of variation and change that are difficult, costly or impossible to control. These sources (sometimes referred to as “noise”) may include such factors as environmental conditions within a factory, minor variations in raw material, or differences in how individual customers use the product. Robust designs perform as intended despite these noise factors.

A commonly used method to achieve robustness is “parameter design,” in which the optimum parameters of key product and process characteristics (e.g., material composition, processing time, pressure, etc.) are determined such that the product is least sensitive to “noise” factors. The selection of these parameters and their settings is accomplished using statistically designed experiments, among which Taguchi fractional factorial experiments are perhaps the best known. Experience indicates that application of these techniques results in products of superior quality, while achieving significant cost reductions.

4.2.2.5 Geometric Dimensioning and Tolerancing (GD&T)

GD&T is a methodology applied to the preparation of engineering drawings or other media to more clearly describe design intent. It provides the dimensions of a component and its tolerances in a way that eliminates confusing and inconsistent notes, implied datums and incomplete specifications. One of the primary benefits of this technique is that it resolves the common engineering drawing deficiency of not identifying datum reference points from which repeatable measurements can be made. The identification of such reference points is critical to the assembly process and to understanding the impact of variation of individual components in the assembly. Despite its obvious advantages over other methods, GD&T is still not universally applied across the aerospace industrial base, hence its inclusion in this guide. The ANSI standard, Y14.5M-1982, provides instruction and ground rules for proper application of this technique. (Source: “Defect Prevention,” Appendix II, Victor E. Kane, 1989).

4.2.2.6 Process Variability Reduction (PVR)

Every production process results in some variation in the product characteristics it generates. The product characteristics may be in terms of physical, material, or chemical properties. In general terms, the product’s characteristics represent output variables of the process. Input variables are factors such as: the quality of materials used; the condition of the equipment; the training and skill of the operator; the values of nominal control settings; and the adequacy of fixtures or jigs that support and position materials. For a stable production process, the output variability is generally seen as a normal distribution about some average value. The average value may also vary with time, but in a stable process, this variation is relatively small. In the broadest sense, process control constitutes the quality assurance provisions for ensuring delivered products meet all requirements. For stable, capable processes, this generally translates to ensuring that all input variables are properly controlled with some form of feedback from output variables.

Reducing variability in key product characteristics, by definition, always results in a relative benefit. The Taguchi Loss Function applies to such characteristics, showing the closer to the nominal, or target, value the characteristic is, the more reliable the product

will be. PVR is a systematic approach for continuously seeking sources of variation within the key product characteristics and process parameters that control those characteristics and then developing means for eliminating the sources. Such means can include additional design improvements that would increase design robustness, eventually eliminating the applicable characteristics from the list of those considered key. After the key product characteristics have been identified, along with the key manufacturing process parameters that control them, basic statistical process control techniques can be used to ensure the processes are capable and stable (e.g., \bar{X} bar/R charts).

Tools that can be used to seek out sources of variation in processes include the following.¹:

- a. Process flow charts can show the complexities within a process and interrelationships among process steps. Experience indicates that the excessive or redundant handling or movement of product, and the inefficient sequencing of process steps can be eliminated or reduced through use of process flow charts.
- b. Pareto charts can help prioritize improvement opportunities identified using a variety of analytical techniques.
- c. Cause and effect (Ishikawa) diagrams can also be used to help show interrelationships and prioritize improvement activities.
- d. Design of Experiments (DOE) analytical techniques can eliminate or control sources of variation by identifying and addressing the most influential sub-process sources of variation.
- e. The Poka-Yoke or fail-safing technique involves implementation of hardware, software or monitoring instrumentation sufficient to "lock-out" or eliminate process failure modes. This approach is a fundamental defect prevention tool intended to preclude the possibility of process errors that could result in product defects.

4.2.2.7 Control of variation in the measurement system Measurement processes exhibit variation just as manufacturing processes do. For this reason, it is important that measurement equipment repeatability and reproducibility studies be conducted when performing process capability studies to ensure variation in the measurement devices variation is not consuming an excessive amount of the design tolerance. Such studies of the capability and natural variation inherent within measurement equipment are often called gage variation, or repeatability and reproducibility (Gage R&R) studies. They differ from the traditional calibration/metrology programs essentially in the details of the information obtained about the gage's accuracy, capability and reliability. Inherent variation within the gage is known as repeatability and can be measured by having one operator take repeated measurements of one characteristic on one part. Reproducibility takes into account differences between operators. Results of Gage

¹ This discussion regards improvements to stable, capable processes that aren't producing any nonconforming product. Nonconformances result from processes that are out of control and/or incapable and need to be handled with a closed loop corrective action system that identifies and eliminates their root causes.

R&R Studies are made statistically valid by controlling possibly superfluous sources of variation and in the number of trials used to obtain data. They are expressed in statistical terms and related to particular part characteristics by determining how much engineering tolerance for the characteristic is taken up by inherent gage variation.

4.2.2.8 Root cause, closed loop corrective action

Because even defect prevention will never be 100% effective in eliminating the production of defective product, some form of the material review and corrective action system used in basic quality systems is still required. However, basic quality systems have tended to place the greatest emphasis on the disposition of defective material (i.e., determining whether it should be used as is, repaired or reworked, or scrapped), and relatively little emphasis on correcting the cause of the defect. In contrast, defect prevention emphasizes prevention of the defect's recurrence, whether the deficiency was found in incoming, in-process, or completed parts and assemblies. Corrective action normally involves the use of multi-functional teams and formal problem solving techniques, combined with high-level management attention and tracking. This results in evaluation and implementation of changes in designs, manufacturing processes, tooling, work instructions, training, etc., to ensure the problem does not recur.

4.2.2.9 Continuous Improvement (CI)

The basic objective of CI is to constantly reduce the cost to deliver a product of increasing quality. This is achieved by assessing the root causes of both process and product variability and reducing or eliminating their influence through the institution of cost-effective changes.

Process CI: For production processes, CI initiatives may include such things as additional operator training, more frequent equipment maintenance, and refinement of control settings or improvements to fixtures. CI should also be applied to other business/management processes which, if not reliable and repeatable, may increase variability. For example, while production/manufacturing variability may be under control and constantly being reduced, out-going product quality may be compromised by ineffective quality assurance, document control, or configuration management systems. It is important that CI be focused on production, business and management processes throughout the lifecycle to ensure a cost-effective, quality product.

A tool that many companies have found useful for implementing continuous process improvement is Kaizen. This Japanese word means gradual, unending improvement. It is the systematic foundation of an organizational culture whereby all members of the organization are constantly seeking ways to perform tasks more efficiently and effectively. Kaizen results in everyone doing little things better and setting/achieving higher and higher standards. While small, individual changes may not appear to mean much, the many gradual changes that result when a company implements Kaizen often add up to significant measurable improvement over time. Kaizen implementation also often results in large, immediate improvements as the need for changes in factory layouts, product flow, etc., are discovered and implemented.

Product CI: Another aspect of CI is the evaluation of the design to determine if there are cost-effective ways to make it more robust (more tolerant to variation). As

discussed earlier, design robustness can be improved through redesign, resulting in a reduction of key product characteristics. As part of such an effort, designers would consider how variability associated with the factory infrastructure (inventory control, material handling, etc.) would affect the variability of product components, subassemblies, assemblies and related manufacturing/fabrication processes. The designers would then take actions to reduce such product variability through design modifications and, to the extent that robust design solutions are not cost-effective, recommend process improvements for mitigating the effects of the variability.

To facilitate CI, world-class manufacturers employ systems to collect and analyze process and product metrics which provide insight into product quality, delivery, performance, cost, and manufacturing efficiency. These systems use the data collected to measure effectiveness of CI initiatives as well as to identify areas for additional investigation and corrective action. These systems also can alert the supplier or customer to anticipated contract delivery schedule delinquencies, production difficulties, or delays.

4.2.2.10 Defect Prevention Elements and Integration of Subcontractors

Given that subcontractors may account for a significant percent of the work content of aerospace acquisition programs, effective implementation of defect prevention requires that the supplier determine those defect prevention elements that should be reflected in their individual subcontractors' processes. Defect-free subcontractor products also facilitate such cost saving practices as just-in-time delivery and direct ship to assembly/stock, enabling assembly plants to eliminate redundant receiving inspection operations.

4.3 ENABLING BUSINESS PRACTICES

4.3.1 Project Funding Profile

Successful implementation of manufacturing process risk mitigation measures requires adequate up-front program funding. Many examples can be found in which government contracts have been awarded with minimal funding for leading-edge product and process design analyses and trade studies. This often results from the familiar dilemma of resolving current-year budget shortfalls while "keeping a program alive". Resources are usually found to correct the flaws of inadequate systems engineering later in the program life cycle at greatly increased cost. Program managers must be proactive in seeking and obtaining the necessary resources in the development phase to effectively implement defect prevention risk mitigation measures.

4.3.2 Contract Award/Incentive Fee Pool

With acquisition reform, the traditional role of invasive government oversight of contracts is changing. The new thrust is one of government insight and contractor self governance. In order for this new way of doing business to succeed, -- i.e., for the needed change to take hold within the tradition-bound aerospace acquisition culture -- both the government and contractors may need to make some adjustments. Primarily, the government must do all it can to ensure the right contractor is chosen for the right

job by increasing the rigor of source selection. The importance of past performance and contractor implementation of systems that will reduce potential risks to the quality of the product must be elevated. Once this is accomplished, however, it may also be useful to build into the contract tangible and significant incentives for world-class quality in order to help ensure the chosen contractor institutionalizes the needed culture change within their company.

Traditional incentive and Award/Incentive Fee pool structures have been based on cost, schedule and technical performance. It is recommended that program managers consider establishing a fee pool specifically tied to defect prevention metrics. Appendix B discusses some possible methodologies in this area for consideration. However, since a wide variety of metrics and incentive arrangements can be constructed, program-unique features and constraints should drive the selection of any incentive structure.

5. DEFECT PREVENTION BY ACQUISITION PHASE

This section provides sample defect prevention SOO/SOW language for each of the four major acquisition phases. For the development phases, this section also provides recommended defect prevention language for RFP Sections L and M. **Note that the contract language contained herein is NOT mandatory.** While the proposed language identifies specific tools and techniques, it is not the intention to tell offerors specific tools **to be used**. Rather, it is to identify the types of tools and techniques that have been recognized to support a defect prevention approach. In every case it should be adapted, modified and tailored to the extent deemed necessary for consistency with the specific conditions of the acquisition at issue. In some cases it may be necessary to add requirements for specific, program-unique defect prevention practices related to unique needs in the areas of facilities, handling, workmanship, controls (e.g., electrostatic discharge, foreign objects), etc.

5.1 DEVELOPMENT RFPs

SOOs and Sections L and M should explicitly address defect prevention practices. The suggested language included herein is provided to assist you in tailoring your solicitation to the needs of your program. Offerors should be required to provide a detailed response to Section L defect prevention issues. Buying activities should evaluate the proposals based on the extent to which the offeror demonstrates an understanding of, and ability in, defect prevention practices and proposes implementing effective practices consistent with program needs. It is recommended that the defect prevention practices be included in the technical area under the evaluation factors for award, for two reasons: (1) The practices addressed herein are principally technical in nature, a component of Systems Engineering; and (2) inclusion in the technical area will generally increase the influence of defect prevention practices in determining award of the contract. The need for actual contractual commitment to defect prevention practices would depend upon the assessed risk and criticality to program success.

5.1.1 Concept Exploration (CE) Phase, or NASA Phase A

Note: It is assumed that this phase is competitive.

5.1.1.1 Guidance SOO/SOW Language for CE/Phase A

The following language is provided for guidance:

The government's objective is for the supplier to identify the risks associated with each design/technology alternative under consideration and will include those risks as factors in the process of developing the ultimate design and manufacturing solution(s). The supplier is responsible for determining those defect prevention elements that should be reflected in their individual subcontractors' processes.

5.1.1.2 Guidance Section L language for CE/Phase A

The following language is provided for guidance:

Describe the planned approach for identifying and mitigating the manufacturing process risks (e.g., the risks related to developing stable and capable processes, to minimizing the need for engineering changes, to preventing defects, etc.) associated with each design under consideration. Describe how knowledge of these risks will be utilized in the process of developing and refining a design solution or design alternatives.

5.1.1.3 Guidance Section M Language for CE/Phase A

The following language is provided for guidance:

Proposed approaches will be evaluated based upon:

- (1) The extent to which they employ disciplined, structured processes (versus ad hoc or anecdotal) for identifying and mitigating manufacturing process risks (e.g., the risks related to developing stable and capable processes, to minimizing the need for engineering changes, to preventing defects, etc.).
- (2) The extent to which the processes for identifying and mitigating manufacturing process risks are integrated with the overall systems engineering process.
- (3) The extent to which manufacturing process risk areas in proposed concepts have been identified and the assessed probability that proposed risk mitigation will be successful.

5.1.2 Program Definition and Risk Reduction (PDRR) Phase, or NASA Phase B

Note: It is assumed that this phase is competitive.

5.1.2.1 Guidance SOO/SOW Language for PDRR/Phase B

The following language is provided for guidance:

The government's objective is for the supplier to define and mitigate the manufacturing process risks associated with the design solution through the development of producible designs, capable fabrication and assembly processes, and associated controls. This includes activities such as the following:

- (1) Developing and implementing an approach for the identification of key product characteristics. Key product characteristics are the features of a material or part whose variation has a significant influence on product fit, performance, service life, or manufacturability.
- (2) Identifying manufacturing process risks (e.g., the risks related to developing stable and capable processes, to minimizing the need for engineering changes, to preventing defects, etc.) associated with the evolving design solution, and developing and implementing appropriate design alternatives and risk reduction efforts. The supplier is responsible for determining those defect prevention elements that should be reflected in their individual subcontractors' processes.

5.1.2.2 Guidance Section L language for PDRR/Phase B

(Note: An integral element of the source selection process should be an assessment of the offeror's past performance in defect prevention. It is vitally important to select a supplier with a proven record of good performance. The Past Performance language in Section L relative to the manufacturing process risk assessment would typically be consolidated with that of other areas such as cost control, program management, technical performance, etc. into a single location within Section L. For the purposes of this guide, the Past Performance portion of Section L is left to the local buying activity's discretion and is not addressed herein.)

The following language is provided for guidance:

Propose and discuss any defect prevention practices to be employed for this acquisition. To facilitate government evaluation methods, provide rationale for each such method, indicating how it helps to meet the SOO/SOW paragraphs on defect prevention.

Describe how key product characteristics will be identified and how existing manufacturing process capabilities are considered in the assessment of manufacturing process risks associated with the evolving product design. Define how manufacturing process risk assessments are fed back to product design efforts to ensure that producibility considerations are included in the evolving product design.

5.1.2.3 Guidance Section M Language for PDRR/Phase B

The following language is provided for guidance:

Proposed approaches will be evaluated based upon:

- (1) The extent to which they employ disciplined, structured processes (versus ad hoc or anecdotal) to identify and mitigate manufacturing process risks (e.g., the risks related to developing stable and capable processes, to minimizing the need for engineering changes, to preventing defects, etc.).
- (2) The extent to which the processes for identification of key product characteristics and identification/mitigation of manufacturing process risks are integrated with the overall systems engineering process
- (3) The extent to which the proposed approaches reflect the integration of manufacturing process risk reduction efforts into the planning for this program.

5.1.3 Engineering and Manufacturing Development (E&MD) Phase, or NASA Phase C

Note: Low Rate Initial Production (LRIP, or NASA Phase D) is an element of this phase, and this phase is considered to be competitive.

5.1.3.1 Guidance SOO/SOW Language for E&MD/Phase C

The following language is provided for guidance:

The government's objective is that the supplier has:

- a. Producible designs that fulfill specified requirements by the start of low rate initial production (LRIP) or NASA Phase D.
- b. Stable, repeatable, capable fabrication and assembly processes and tooling by the beginning of LRIP or NASA Phase D.
- c. Plans for controlling production processes in place by start of LRIP or NASA Phase D; implemented in LRIP or NASA Phase D
- d. Plans for remediating the root cause of non-conformances in place by the start of LRIP or NASA Phase D, implemented in LRIP or NASA Phase D.
- e. Integration of subcontractors into the supplier's approach for achieving the above objectives.

5.1.3.2 Guidance Section L language for E&MD/Phase C

(Note: An integral element of the source selection process should be an assessment of the offeror's past performance in defect prevention. It is vitally important to select a supplier with a proven record of good performance. The Past Performance language in

Section L relative to the quality assessment would typically be consolidated with that of other areas such as cost control, program management, technical performance, etc. into a single location within Section L. For the purposes of this guide, the Past Performance portion of Section L is left to the local buying activity's discretion and is not addressed herein.)

The following language is suggested:

Propose and discuss defect prevention practices to be used for this acquisition. To facilitate Government evaluation, provide rationale for each method, indicating how it helps to meet the SOO/SOW paragraphs on defect prevention. For purposes of this solicitation, defect prevention practices address such activities as:

- (1) Identifying and controlling the key product characteristics and document those characteristics on the applicable drawing(s). Key product characteristics are the features of a material or part whose variation has a significant influence on product fit, performance, service life, or manufacturability.
- (2) Identifying those fabrication and assembly processes that control key product characteristics; and verifying the capability and stability of those processes. Production representative tooling and documentation (including process specifications and work instructions) are usually employed in the verification effort sufficient to demonstrate that the required performance, quality, production rate, and manufacturing efficiency is achievable.
- (3) Applying drawing techniques that relate the dimensions and tolerances for each part to its functions and features.
- (4) Analyzing and controlling tolerance stacking in each assembly.
- (5) To the maximum practicable extent, concurrently developing the system design, tooling, fabrication and assembly processes, manufacturing sequences, process controls, and work instructions.
- (6) Explicitly considering manufacturing process capability, manufacturing efficiency, and producibility as factors in the applicable design trade studies.
- (7) Implementing effective closed-loop controls for identifying and eliminating the root causes of nonconformances. This includes taking appropriate action to change or eliminate technical requirements that nonconformance data analysis indicates are unreasonable or unnecessary and to improve or change processes not capable of meeting requirements.
- (8) Selecting, integrating, and managing subcontractors into the defect prevention practices.

5.1.3.3 Guidance Section M Language for E&MD/Phase C

The following language is provided for guidance:

The proposed defect prevention practices will be evaluated on the extent to which they are adequate for program needs and meet the following criteria:

- (1) The extent to which the proposal reflects the integration of the defect prevention practices into the planning for this program. This includes the integration of subcontractors into the approach for achieving the defect prevention objectives. The proposed timing of these activities and tasks will be assessed for the extent to which it facilitates accomplishment of the following prior to LRIP:
 - Producible designs
 - Stable, capable processes
 - Plan for controlling production processes
 - Plan for remediating the root cause of non-conformances.
- (2) How well the proposed approaches contribute to manufacturing process, quality, cost and schedule risk reduction.
- (3) How well the proposed approaches facilitate the prevention of defects. The supplier is responsible for determining those defect prevention elements that should be reflected in their individual subcontractors' processes.

5.2 FULL PRODUCTION PHASE

Note: The RFP for this phase is assumed to be sole source.

5.2.1 Guidance Full Production Phase SOO/SOW Language

The following SOO/SOW language is provided for guidance:

The government's objective is that, through execution of defect prevention practices, the supplier will have:

- a. Stable, repeatable, capable fabrication and assembly processes and tooling.
- b. Effective production process controls in use.
- c. Use of an effective system for remediating the root cause of non-conformances.
- d. Integration of subcontractors into the supplier's approach for achieving the above objectives. The supplier is responsible for determining those defect prevention elements that should be reflected in their individual subcontractors' processes.

APPENDIX A

JACG DOCUMENTS ON BASIC QUALITY

APPENDIX B

INCENTIVES

One of the intended outcomes of defect prevention practices is continuous improvement to reduce risks and improve program cost, schedule and technical performance. An added benefit of continuous improvement is often improved product reliability as design robustness is increased and process variability is reduced. However, mandating continuous improvement systems in government contracts has often proven to be ineffective without specific contractual incentives. Government contractors simply do not face the same marketplace pressures that drive continuous improvement as commercial companies. Even a practice widely recognized to be beneficial -- variability reduction -- might be implemented in an ineffective manner unless adequate incentives are provided to ensure contractors and subcontractors want to develop and implement improvements because it is in their best financial interest to do so. Coupled with the fact that contractual language will no longer dictate methods, but instead rely on contractor processes for meeting contractual product technical performance requirements, incentives to improve those processes become more important. For these reasons, it is suggested that the implementation of appropriate monetary incentives be considered through the use of contractual Award/Incentive Fee criteria.

Award/Incentive Fee criteria ought to be program-unique, taking into account the mission of the program, the product's key product characteristics, capability of the contractor(s) and other unique features of the program. They also ought to be jointly developed and negotiated with the contractor(s), government plant representatives, and users to ensure the buy-in of all stake-holders, which in turn will help ensure appropriate resources are applied to the improvement efforts. In addition, soliciting inputs from the user community for the product will strengthen the critical early communication link between the user, the program office and the contractor. It may also have the added benefit of helping to identify what the users feel is most important, a critical determination in identifying key product characteristics. The following attributes of good incentive criteria need to be kept in mind when developing Award/Incentive Fee criteria:

1. They must be relevant to the program and consistent with program mission, goals, operational requirements, etc.
2. They must be consistent with contract requirements and other program documents.
3. They must be measurable and the measurement systems must be reliable, comprehensive and trustworthy.
4. They must be beneficial to both parties. In other words, the benefits to be derived by the government must outweigh all costs, including administration of the Award/Incentive Fee plan, and the potential benefits for the contractor must make it worth their while to put appropriate effort into finding ways to improve current performance.

5. Taken as a whole, they should incentivize continuous improvement. In other words, they shouldn't have an end point goal, which, when achieved, will result in termination of the improvement effort prior to the end of the Award/Incentive Fee period due to lack of incentive to continue. Although it may be useful to have individual criteria that incentivize accomplishment of some task (e.g., identification of all key product characteristics on drawings), there should be sufficient additional criteria to incentivize continuous improvement.
6. Related to the last two points, the criteria should reflect "stretch" goals that challenge the contractor, but are also achievable.
7. They should not be "etched in stone", but should allow for review and renegotiation. This is especially true for criteria incentivizing complete accomplishment of particular tasks as discussed under 5, above.

Rating categories should be defined to determine the amount of Award/Incentive Fee that will be paid based on the contractor's performance in defined criteria over a defined period of time. Due to the fact that no matter how well planned, incentive criteria may not produce the desired results because they are too difficult or too easy to attain or because they simply don't reflect actual contractor performance, flexibility should be built into the incentive system. One means of doing this is for the rating criteria to provide the Fee Determining Official with some leeway (a range) to determine the exact amount of the fee to be awarded. An example might be as follows:

RATING	PERCENT OF POSSIBLE AWARD/INCENTIVE FEE TO BE PAID
Excellent	91 - 100
Good	71 - 90
Satisfactory	51 - 70
Marginal	1 - 50
Unsatisfactory	0

Award/Incentive Fee criteria can be developed for any useful metrics in accordance with the attributes of good criteria noted above. It is recommended that a variety of metrics be used to provide a more comprehensive depiction of program performance and to prevent over-emphasis on a particular measure at the expense of others. For each metric, cost, schedule and/or performance goals can be developed and incentives applied for progress toward or beyond them. In addition, it may be useful to connect metrics together so that, for example, poor performance in one area will prevent award of fees in other areas until performance is at a minimal level across the board.

When considering metrics to be used as incentives criteria, it is important to determine what behaviors outside of the norm are desired. For example, the attributes of defect prevention practices which would be helpful for ensuring success of any particular program could be considered for incentivization. The table on the following page provides examples of metrics that may be developed and used for incentivizing implementation of defect prevention practices for EMD and beyond. Note that these are

essentially process oriented metrics. Individual programs may want to incentivize product performance attributes as well.

In addition to those suggested in the table, other possible Award/Incentive Fee criteria can include value-engineering incentives for changes that make designs more robust, improve first-pass test yields, increase management responsiveness, make progress toward training goals, etc. Another source of information are the weighted guidelines for negotiating profits found in the Defense Supplement to the Federal Acquisition Regulations. These could be adapted to reward affordability improvements.

DEFECT PREVENTION PRACTICES PERFORMANCE ATTRIBUTES	ASSOCIATED CANDIDATE METRICS FOR AWARD/INCENTIVE FEE CRITERIA
Design practices result in the identification, documentation and control of key product characteristics	<ul style="list-style-type: none"> - Key product characteristics captured in product definition data - Percentage of key product characteristics for which control methods have been defined
Design practices result in robust designs that are insensitive to variability in manufacturing processes and minimize part complexity	<ul style="list-style-type: none"> - Part complexity index value or design efficiency value (from Design-for-Assembly/Design-for-Manufacture analysis) - Percentage of critical failure modes among all failure modes (include both product and process FMECA)
Design practices minimize tolerance stack-up, interference and assembly alignment problems	<ul style="list-style-type: none"> - Percentage of drawings developed using geometric dimensioning and tolerancing techniques
use of stable, capable manufacturing processes as a basis for product acceptance in lieu of inspection and test	<ul style="list-style-type: none"> - Percentage of key product characteristics to be controlled by existing, fully characterized manufacturing processes - Percentage of part numbers accepted on basis of manufacturing process capability - Appraisal costs (i.e., inspection and test) as a percentage of total quality costs (prevention, appraisal and failure)
manufacturing processes and tooling controlling key product characteristics (i.e., "key" processes) are stable and capable	<ul style="list-style-type: none"> - Percentage of key processes with Cpk values at 1.33 or higher or with equivalent means of process control (e.g., adaptive machine control, poka yoke (mistake proof) control, etc.)
variation associated with measuring and test equipment is accounted for when determining process capability	<ul style="list-style-type: none"> - Percentage of key manufacturing processes not already demonstrated to be stable and capable on which gage repeatability and reproducibility studies have been performed
(1) the rapid disposition of defects; (2) rapid and accurate identification of the root causes of defects; and (3) the implementation of effective corrective action	<ul style="list-style-type: none"> - Number of repeat nonconformances - Number of open nonconformance investigations - Age of nonconformance investigations - Average disposition time per nonconformance - Percentage of "use-as-is" dispositions - Failure (e.g., scrap, rework and repair) costs as a percentage of total quality costs (prevention, appraisal, failure)
continuous variability reduction for key product characteristics and processes	<ul style="list-style-type: none"> - Cpk values, yield rates or defects per million opportunities for selected characteristics and processes over time
Suppliers are fully integrated into the defect prevention practices	<ul style="list-style-type: none"> - Percentage of suppliers who are certified for ship-to-assembly/stock - Percentage of supplier items subject to re-inspection upon receipt - Percentage of nonconformances (and/or failure costs) attributable to suppliers

NOTE ON KEY PRODUCT CHARACTERISTICS AND OTHER SIMPLE "BODY COUNT" METRICS: Although it is important that all key product characteristics be identified, the fewer there are, the more robust the design will be. For this reason, it may be helpful to develop incentive criteria such as those suggested for reducing key product characteristics previously identified. Of course, with all incentives utilizing simple counts (e.g., defects), it is important to balance out such criteria to prevent artificial inflation of early measurements for the purpose of making it easier to show incentivized improvements later on.

Following are two specific examples of Award/Incentive Fee criteria to show how they might be developed. Their specific applicability to any particular program will depend on

attributes of the program, as discussed earlier in this appendix (attributes of good incentive criteria).

EXAMPLE CRITERION 1: Product Variability Reduction:

BASIS FOR DETERMINATION: Selected manufacturing processes are agreed upon by the contractor and buying activity. Statistical data will be collected on these identified processes to determine the control limits based on the statistical capabilities of each process. A process capability index (Cpk) will be measured by taking into account the tolerance limits for the process outputs. A rating will be determined by comparing the measured Cpk with the evaluation criteria shown below. No Award/Incentive Fee will be given for any process until all key processes have a Cpk of 1.00 or greater at the end of the rating period. Once all identified key processes meet this requirement, an Award/Incentive Fee amount will be determined for each identified process that has a Cpk of 1.33 or greater based on the monthly average Cpk of the process for the applicable period. (NOTE: sample sizes and the frequency of determining Cpk each month, so that an average Cpk can be determined, must be agreed to for each process based on statistical data).

EVALUATION: The following factors will be used to determine the amount of Award/Incentive Fee the contractor is entitled to:

Ratings:

Excellent:	Cpk > 2.00
Good:	Cpk = 1.67-1.99
Satisfactory:	Cpk = 1.50-1.66
Marginal:	Cpk = 1.33-1.49

Note in this example that it was set up to require both a minimum level of performance across the board (all key processes must be at a Cpk of 1.0 or greater for any fees to be paid), as well as individual payments for each process having a Cpk above what is widely accepted as the minimum acceptable process capability of 1.33. (Questions such as those regarding the appropriateness of paying an additional fee for “marginal” performance can easily be handled with a change in terminology.) Note, too, that the incentive here might be to reach the minimum in the “Good” category (1.67) but beyond that, due to the larger range before the next level is reached, it may be determined not to be worth the extra effort required to reach the “Excellent” category. Something like this could be done intentionally to try to get contractors to bring all their processes to a desired level of performance, rather than concentrating on one or two easy ones, while still providing some incentive for even further improvement. Other possibilities might be to negotiate different levels for different processes or categories of processes. When negotiating criteria, buying activity personnel should keep in mind what it is they want to achieve with the particular incentive. In addition, of course, criteria such as this one would necessitate correct application of the statistical concepts, such as verification that the applicable processes have normal distributions, correct sampling techniques, agreed-upon confidence levels, etc.

APPENDIX C

GLOSSARY OF SELECTED KEY TERMS

Basic quality system. A quality system based on ANSI/ASQC Q9000 / ISO 9000 series or equivalent.

Geometric Dimensioning and Tolerancing (GD&T). A methodology applied to the preparation of technical data to clearly describe design intent by providing the dimensions of a component and its tolerances in a way that eliminates confusing and inconsistent notes, implied datums and incomplete specifications.

Integrated Product and Process Development (IPPD). The concurrent development of the system design with the tooling, fabrication and assembly processes, manufacturing sequences, process controls, and work instructions.

Joint Aeronautical Commanders Group (JACG). A body chartered under the aegis of the Joint Logistics Commanders and composed of the heads of the aeronautical buying activities of each service, DCMC, NASA, and the Coast Guard.

Key product characteristics. The features of a material or part whose variation has a significant influence on product fit, performance, service life, or manufacturability.

"Robust" Design. A "robust" design results in a product that is insensitive to or tolerant of sources of variation and change that are difficult, costly or impossible to control.

Subcontractor. A contractor with whom the prime contractor in a government contract has contracted for services or products.

Supplier. As viewed by the government buying activity, the prime contractor in a contract.