A FIVE STEP APPROACH TO
ACCEPTABLE QUALITY IN PRODUCTION HARDWARE

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ABSTRACT

This paper describes a systemic approach to assure production line hardware are true quality products. The process is not intended to replace existing quality assurance procedures or controls; it augments them. It bridges gaps in the integration of engineering, manufacturing, and quality assurance by focusing a small amount of effort from all three disciplines toward quality improvements.

INTRODUCTION

"Not built to print" could characterize the reason for 50 percent or more of the flight test mishaps on production missiles. The percentage may be lower for piloted aircraft, but is still substantial. Missile weapon systems (and unpiloted aircraft) are particularly vulnerable to quality defects because of their "single-thread" or nonredundant design. Poor quality in production hardware has caused part of the R and M 2000 Program effort to be directed at quality improvements.

The following process is intended to develop a systemic approach to assure production line hardware are true quality products. A quality product is built to print, meets all appropriate requirements, and is free of workmanship errors. The following process is not intended to replace existing quality assurance procedures or controls. It is meant to bridge gaps in the integration of engineering, manufacturing and Quality Assurance (QA) functions. It focuses a small amount of effort from all three disciplines toward quality improvements in production hardware. The procedure was developed by Aeronautical Systems Division (ASD) engineers working on weapon system improvements, but may be applied to any manufactured product.

The following terms, used primarily in STEP 1, are defined for clarity.

Piece-parts are the lowest level of nondestructive disassembly to which a system, assembly or subassembly can be reduced. Welded or brazed pieces are considered one part; soldered, bonded, glued or crimped connections can be disassembled. Piece-parts appear in the list of materials, or parts list, of drawings. Any assemblies called out in the parts list must be further broken down to their piece-part components.

In-process testing refers to all checks, tests and verifications performed from start to finish of the manufacturing and assembly operation. It includes such things as off-site vendor tests and incoming receiving inspection, as well as the final Acceptance Test Procedure (ATP).

A critical piece-part is one whose absence or failure to function as designed could degrade mission performance.

Redundancy refers to two or more piece-parts performing the same function for the operational configuration.

Before describing the process, a few words about piece-parts and in-process testing may be beneficial. A few parts, such as explosives and burst discs, cannot be nondestructively tested. Instead, substitution of a very rigorous acceptance qualification test program and a no-fail lot sampling test criteria are in order. Occasionally, the last connection point of an electrical, hydraulic or pneumatic system cannot be fully tested. (You can test for electrical continuity, but not current carrying capability; or you cannot test for leaks.)

The five step approach to acceptable quality in production hardware is as follows.

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STEP 1. PIECE-PART CHECK - A check of the complete piece-part list (including consumables) against in-process testing.

Ideally, in-process testing would verify the presence and function(s) of every piece-part, including those which are not critical. Testing of noncritical items, however, is a luxury that can not be afforded from either a cost or a man-hours used point of view. Noncritical item tests should be eliminated whenever possible, unless they are incidental to critical item tests.

A few piece-parts in an assembly or subassembly may have multiple functions; care must be exercised to ensure all critical functions are tested or verified. A prioritized checklist for in-process verification of critical piece-part functions is as follows:

a. In-process testing for presence and function(s). This includes redundant parts.
b. In-process testing of functions performed by redundant parts without identifying which part performs the function.
c. An independent inspection verification that the piece-part is installed. Some parts, by their very nature, will perform their function when installed. They do not require test verification (symmetrical spacers, back-up rings, and washers are a few examples.)
d. An independent inspection verification that the piece-part is correctly installed. Any part (not tested) that will not function if improperly installed should at least have an independent verification made that the installation was correct.
e. Partial testing of overall functions.

Obviously, the lower one goes down the checklist, the greater the risk of an undetected quality problem. Risk also increases with the number of critical piece-part verifications that occur lower in the checklist. A desirable goal is to go no lower than c; realistically one or two piece-parts may fall under d or e. The nature of the piece-part and the functions it performs will determine if d or e verification is the greater risk. For example, d is better than e for a thrust bearing not tested with an axial load. However, e is better than d for an O-ring tested only at low pressure, even though high pressure leakage could cause concern.

It is impossible to present hard-and-fast rules on how far to carry this process. Many decisions will be subjective in nature. Increased testing reduces program risks, but increases costs. Most engineers have a propensity for testing that must be kept under control. The goal is to prevent critical component deficiencies or "quality problems" from being discovered by flight test. Because of the increased reliance on nonredundant systems in missiles, a critical component deficiency can lead to loss of missile or degraded mission performance. The probability of failure (without testing) and the cost of failure must be balanced against increased production costs.

STEP 2. IN-PROCESS DISPREPANCY REVIEW - Review a summary of the prime contractor in-process discrepancy and failure data. The same information is needed from all subcontractors and their suppliers. This data should be available for all piece-parts, including consumables, and subassemblies.

This data should be in a summary format; a one-line computer listing for each discrepancy/failure would normally suffice. The information headings could be listed as:

a. Date
b. Part Identification
c. Nature of Discrepancy or Failure
d. Root cause of Discrepancy or Failure
e. Corrective Action Taken

Care must be exercised that the root cause is adequately identified when possible. For example, a "leaking O-ring" is not sufficient. Why did the O-ring leak? Was it cut? If so, how? Wrong hardness? Wrong size? Poor quality? O-ring "flash" causing problems?

In a similar fashion, the "corrective action taken" does not mean the action taken to correct a specific discrepancy. For example, "replaced O-ring" is not adequate, but "fabricated tool for installation" or "removed wrong sized stock from assembly area" is. The word "none" should be inserted, when appropriate, to denote cases where no corrective action is under consideration.

A uniform method of reporting and recording in-process failure data should be used to maximize results. All in-process failures should be recorded, whether discovered by receiving inspection, assembly line workers, inspectors, or in-process testing. Component adjustments or "tweaking" made in pre-ATP tests should not be reported.

Many contractors already record and use the in-process failure data as a
A review of the manufacturing operations by the design engineer and senior engineers with "hands-on" experience. Even though variations between parts or assemblies may be acceptable, the manufacturing process needs to be changed. The visual inspection needs to be performed periodically. Personnel changes, new processes and different subcontractors are just some of the things that can affect consistency. APPRO and/or DCAS personnel could be effectively used to monitor manufacturing consistency. The summary report should not be confused with FRACAS - Failure Reporting, Analysis and Corrective Action System. FRACAS deals with reportable failures; those which occur during or after a formal ATP, and includes field failures. The summary report would cover only in-process failures not included in FRACAS. Accident and incident investigation teams would find the summary very valuable in formulating investigation plans and procedures. ASD flight control engineers have relied on their experience and the summary information to indicate what flight control components should be reviewed first.

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The summary report would show what piece-parts and subassemblies were experiencing difficulty. In many cases corrective action could be underway before a "smoking hole" indicated corrections were needed. Lowered retrofit costs might even pay for the summary report.

STEP 3. PRODUCT VISUAL EXAMINATION - Thorough visual examination of piece-parts, assemblies and subassemblies.

This visual examination is looking for consistency. When 40-50 piece-parts are carbon copies of each other, the subcontractor normally has his manufacturing operations under control. Even though variations between parts or assemblies may be acceptable, the variations are indications the manufacturing process needs to be changed or closely monitored.

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STEP 4. MANUFACTURING OPERATIONS REVIEW - A review of the manufacturing operations by the design engineer and senior engineers with "hands-on" experience.

One -- or at most two -- senior AF engineers should participate in a manufacturing process review. The review should be conducted primarily by the contractor's design engineer and other senior engineers with practical "real-world" experience. The review should be stressed as a team effort, in which engineering, manufacturing, quality, management and production personnel would examine the manufacturing operations. The goal is better quality and reduced cost.

In far too many cases, the design engineer has not participated in an in-depth review of the manufacturing operations. He can be a great asset in identifying unnecessary and incorrect procedures. Senior practical engineers are desired because they observe worker actions looking for harmful effects, rather than questioning in minute detail the differences between written instructions and worker actions.

Tell production workers they are team members -- and mean it. Ask for their comments and suggestions. Send a copy of the team report to all production personnel who contribute something. Don't be surprised if half of the producibility improvements in the team report come from the workers. Follow through on all workers suggestions; make sure they are kept informed on suggestion status. Don't reject suggestions on the spot; if rejected, explain why -- and preferably in writing. The AF team member should get a commitment from the contractor's management that reprisals against workers will not occur for comments made or production actions observed. Let the workers know that commitment was obtained.

Consider the impact of what is observed on the total program effort. Look for producibility improvements -- mainly Class II changes -- that would save time, effort or money. Will the present procedures and test methods support rate production? For example, automated test equipment. test equipment may have to replace manual test equipment (lead times can be long). Are production deficiencies, identified by test, fed back to production personnel? Look at all segments of the operation; receiving, inspection, storage, production flow, cleaning, lab certification, testing, packaging, shipping, and any off-site operations.

Remember that it may take four or five days of having other team members around before production workers go back to "business as usual." They will then talk more freely to the team. Schedule the "tour" for at least six days (preferably two weeks). An alternative is to have
permanent team members conduct shorter reviews on a regular basis, but at unscheduled times and places. Talk to the workers and get to know them; ask for their help, comments and observations. Find out if the workers understand their job and what "their" piece-part or subassembly does or contributes to the weapon system performance. How well do they understand the assembly operations and in-process testing? For example, are they aware of the assembly operations which are not verified by test or independent inspection (from STEP 1) that are critical for mission completion?

This review is a supplement to, rather than a replacement for, the current manufacturing and QA reviews. It is meant to be a production improvement exercise that reduces field failures and problems. As such, it should reduce the number of "who done it?" and finger-pointing actions which occur when quality problems are identified in the field.

The "team" concept should be carried through the final report and represent a unified position on recommendations and conclusions. The AF representative should insure all differences of opinion are resolved before he returns from the TDY. The contractor's team leader should be tasked with publishing the final report.

STEP 5. FOLLOW-UP INSPECTION - Allow a reasonable length of time for the contractor to implement changes, and then perform a follow-up inspection.

It is sheer folly to assume deficiencies identified in the previous steps will be automatically corrected. A follow-up inspection is necessary. The inspection should be well publicized and scheduled as soon as possible after the team final report is published. The schedule will be driven by piece-part availability and the schedule of manufacturing operations. It may even require two or more trips to complete.

Check the manufacturing instructions to see if all deficiencies identified in STEP 1 PIECE-PART CHECK have been corrected. Is the contractor gathering and publishing the data for STEP 2 IN-PROCESS DISCREPANCY REVIEW? Where is the data going and how will it be used? Have the APFRO and/or DCAS show you how they are performing STEP 3 PRODUCT VISUAL EXAMINATION. You could even choose the three or four parts for the demonstration. Check the deficiencies identified in STEP 4 MANUFACTURING OPERATIONS REVIEW. Most changes should be completed. What is the schedule for those not fully implemented? Arrange for DCAS/APFRO verification when necessary -- and tell them what it will take to satisfy you.