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First Edition

AQS® Guidelines

A guide to AQS continuous improvement expectations

The custodian for this document is:
Boeing Commercial Airplane Group,
Supply Management and Procurement Division, Quality Assurance Department.

Questions related to the content or distribution of this document should be directed to the custodian.

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Table of Contents

1. An Introduction to This Document

The purpose of this document is to provide a description of the requirements in Addendum 1 of D6-82479, Boeing Quality Management System, leading to a better understanding their intent and use.

This document will also aid in achieving economic and quality benefits for the supplier, The Boeing Company and Boeing customers.

1.1 Purpose and Approach of AQS

AQS is a continuous improvement system used to achieve measurable improvements in cost, cycle time, quality, waste reduction, customer satisfaction, and profitability.

AQS is a systematic approach to product and process improvement that can be used in design, production, inspection and testing, as well as in research and business processes. The approach is based on the use of facts, data and statistics, rather than guesswork and opinion.

In the design of new products, AQS improves quality and reduces long term costs by helping producers design quality into the product during the engineering stage of product development.

AQS helps a company systematically improve products, solve problems, and manage and reduce variation through process understanding.

AQS is also particularly relevant during the implementation of Lean Manufacturing (Just-in-time, Toyota Production System or Flow Manufacturing) when product or process problems or excessive variation become an impediment to desired performance.

1.2 Related Documents

D6-82479

Appendix A -- Quality Management System

This section describes the quality system requirements for Boeing suppliers as contained in ISO 9001 as supplemented by AS9100. Depending on the type of procurement, Appendix A or B may be deemed more appropriate by The Boeing Company. Appendix A represents the International Aerospace Quality Standard for Quality Assurance in design, development, production, installation and servicing.

Appendix B -- Inspection and Test Quality System

This basic quality system tailors Appendix A flowdown requirements. Length of production runs, product complexity and consideration for product utilization are determining factors when Appendix B is imposed.

Addendum 1 Advanced Quality System (AQS)

Addendum 1 describes a process for continuous improvement. It includes requirements that emphasize problem solving, understanding and controlling processes, and decreased cost through variation reduction. This section is not a stand-alone quality system and shall be accompanied in contract flowdown by either Appendix A or B. Addendum 1 shall be imposed when variation reduction is required and/or when key characteristics are identified in Boeing design requirements.

In addition, Addendum 1 principles should be implemented

- Whenever and wherever waste is present
- When quality needs improvement
- When customers are not fully satisfied

Addendum 2 Quality System Requirements for Deliverable Software

Addendum 2 describes the quality system requirements for Boeing suppliers who design, develop, install, procure, or maintain deliverable software.

D1-9000-1 AQS Tools

This separate document is a detailed tutorial on the various tools for continuous improvement and those tools referenced in D6-82479 Addendum 1. Among the topics discussed are problem solving, Pareto analysis, process mapping/flowcharting, cause and effect diagramming, key characteristics, statistical process control (SPC), process capability analysis, design of experiments, risk analysis, histograms, and gage variation studies, as well as many other continuous improvement tools.

Addendum 1 Evaluation Matrix

The evaluation matrix will be used by Boeing to evaluate its AQS suppliers, but can be used effectively for internal audits and as a roadmap for companies who desire an effective continuous improvement system.

All these documents are available on the Boeing web site at: http://www.boeing.com/companyoffices/doingbiz/supplier/

2. The AQS Flow Diagrams

2.1 The high level flow
2.2-2.5 Supporting lower level flows

Figure 2.1
AQS Continuous Improvement Process

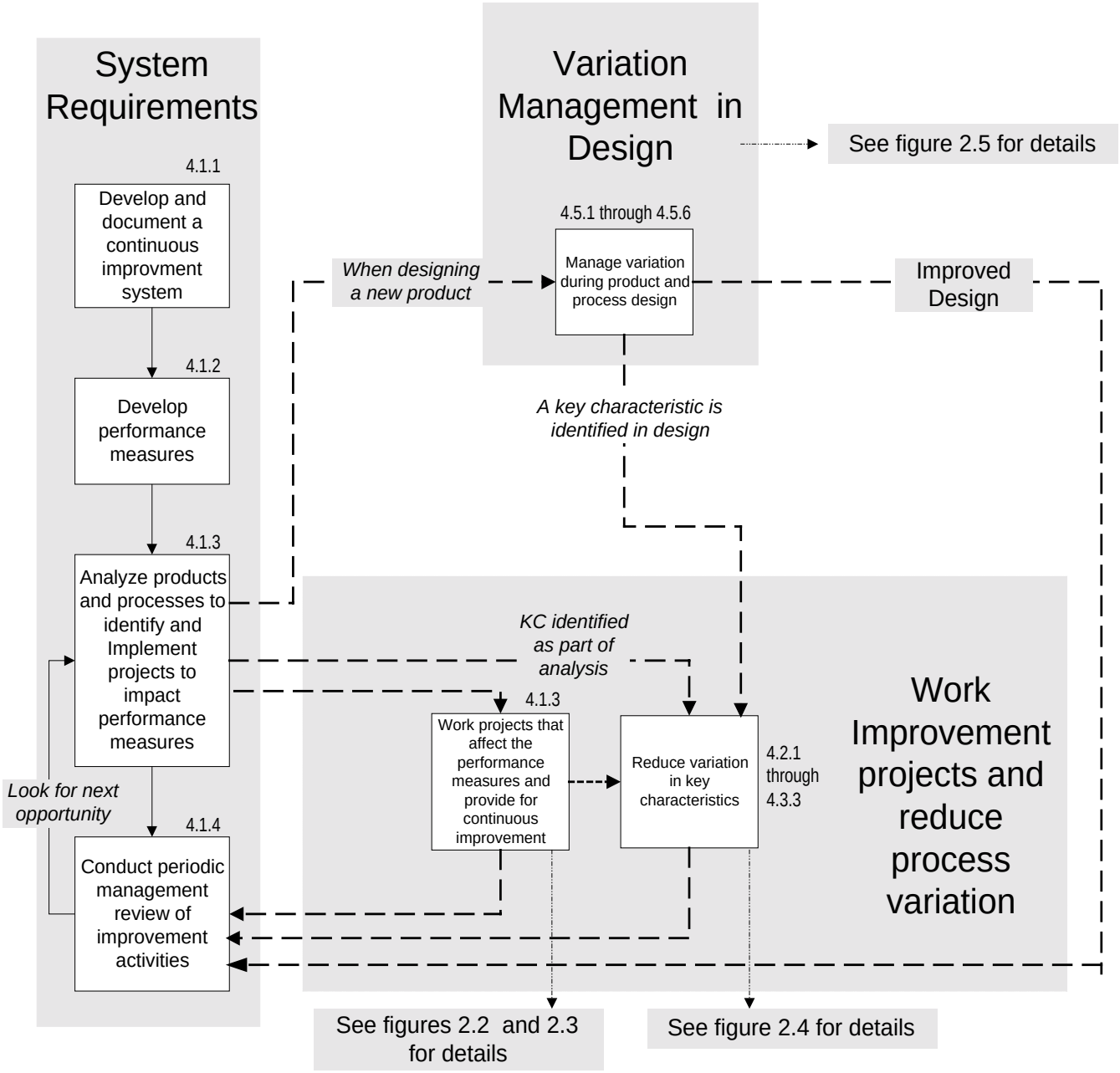
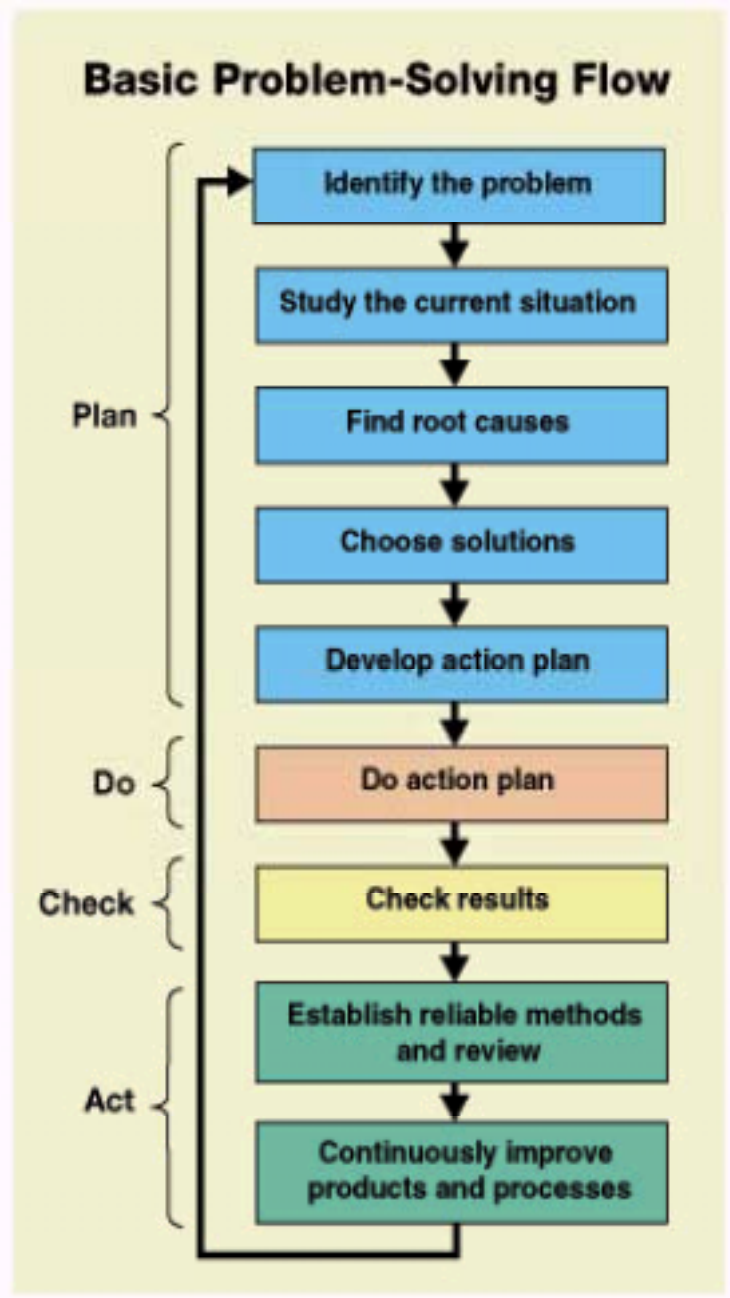


Figure 2.2
High Level Process Flow for Working Projects



For more detail on each step see figure 2.3

Figure 2.3
Process Flow for Working AQS Improvement Projects

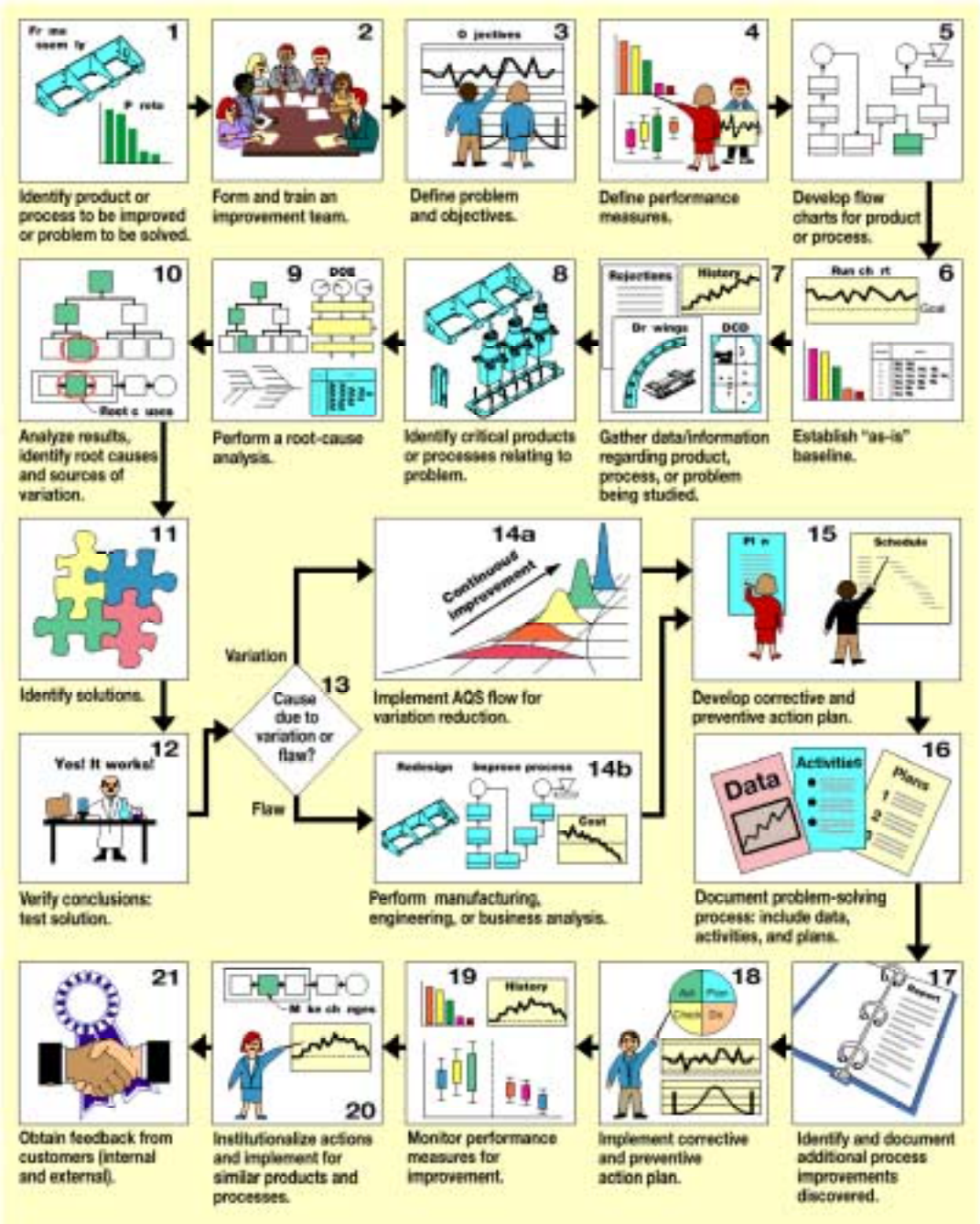
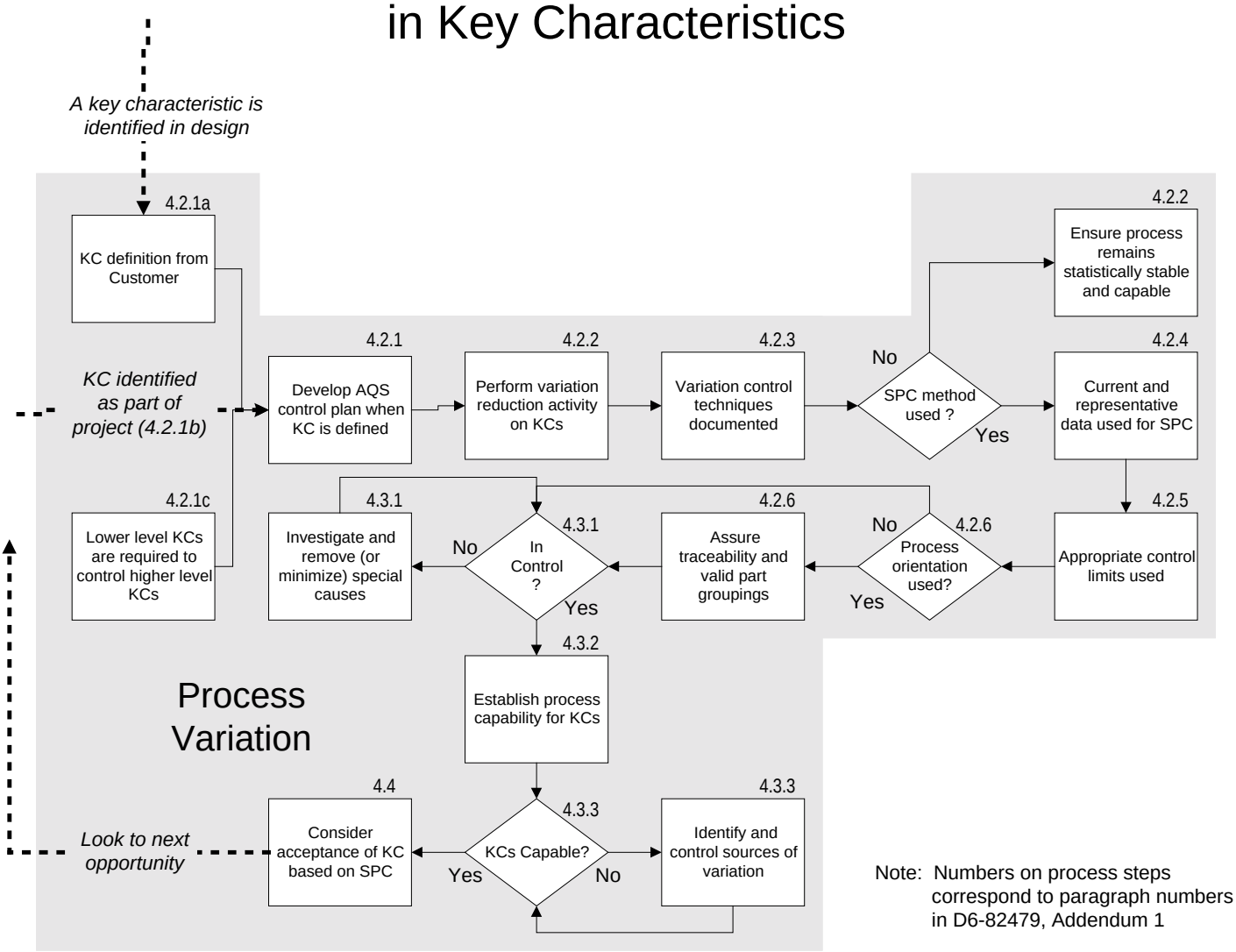
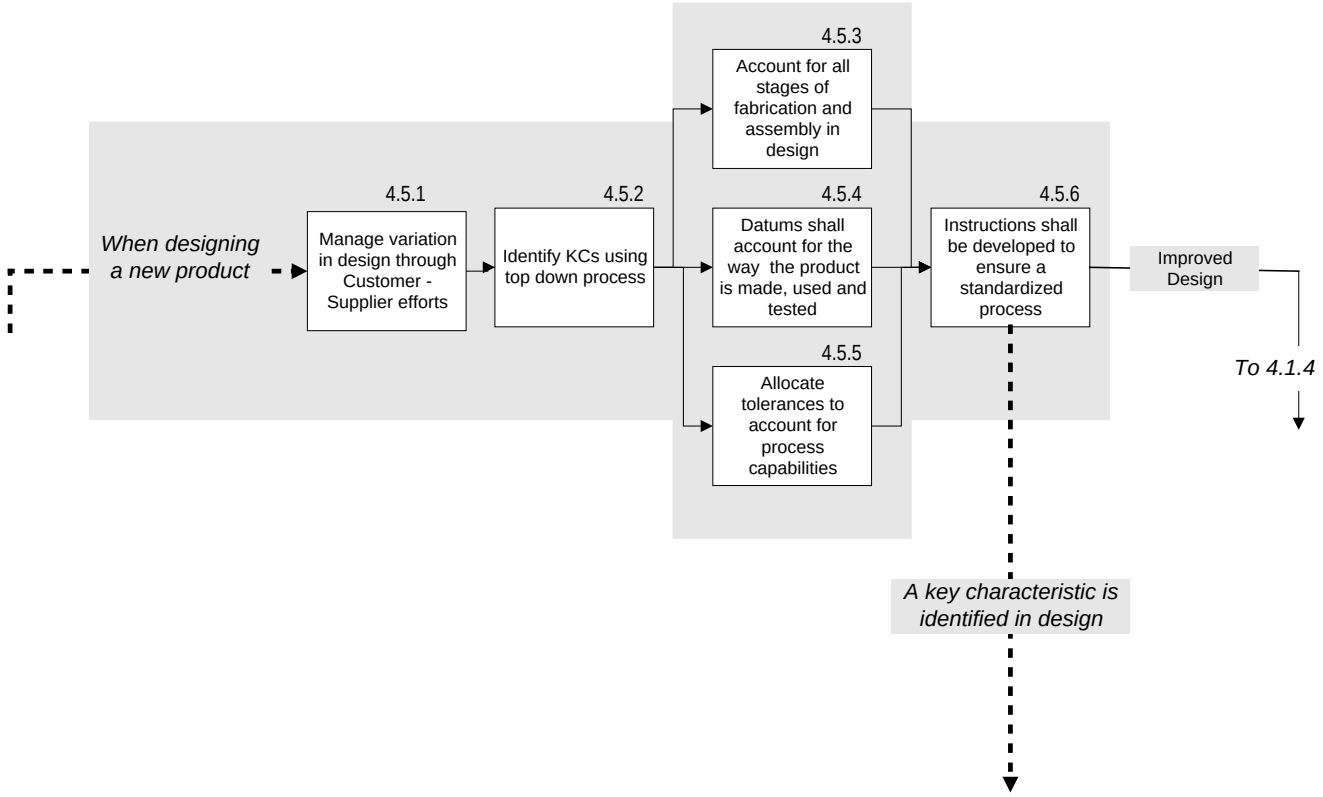


Figure 2.4
Process Flow for Reducing Variation in Key Characteristics



Note: Numbers on process steps correspond to paragraph numbers in D6-82479, Addendum 1

Figure 2.5
Process Flow for Managing and Reducing Variation Through Design



3. Introduction to AQS

Introduction and overview of requirements

When contractually required, the supplier must develop and implement a continuous improvement system, procedures, and documentation that achieve the requirements of D6-82479.

In addition to conformance to contractual requirements, The Boeing Company believes that a high level of performance is beneficial to all companies, especially Boeing suppliers. The AQS continuous improvement process is an effective approach to improving business performance that potentially involves all aspects of business operations.

The AQS continuous improvement process

Figures 2.1 through 2.5 illustrate an approach for implementing the AQS continuous improvement process for reducing variation. AQS includes a process for analyzing customer needs and requirements, establishing business and economic performance measures, reducing cost and waste, and improving quality by systematically analyzing production processes, evaluating current problems, examining the design characteristics of products, reducing the variation of key characteristics and processes, and making processes more efficient.

Where not specifically noted otherwise, Boeing recommends that the terms, concepts, tools and approaches outlined in this document be interpreted as broadly as possible and applied to all processes and elements of supplier operations. With this principle in mind, continuous improvement may be considered to encompass such concepts, practices and programs as Six Sigma, Lean Manufacturing, Statistical Thinking, Kaizen and Process Management.

Management responsibility

Management should be very knowledgeable of the continuous improvement tools and involved in implementing the continuous improvement system. They should be able to provide guidance for the improvement system, and select and support improvement activities and projects with strategic significance to their company.

Performance measures

Once the fundamentals of a continuous improvement system are in place, successful AQS implementation proceeds with complete understanding of the current products and processes, accompanied by sound business performance measures. When defined appropriately, these measures will indicate where improvement efforts should begin and also track their progress and resulting impact. Performance measures should be identified so they reflect value to the customer and help drive the efficiency and effectiveness of internal processes, particularly as improvement projects are accomplished.

Performance measures allow the supplier to apply AQS in the right places in order to gain maximum value and benefit from the improvement activities. They will ultimately provide information regarding the effectiveness of AQS implementation and how much effort to continue applying, and where.

Process and Product Analysis for Continuous Improvement

There are four major categories of activities for continuous improvement using AQS: analyzing processes and products for improvement opportunities, setting up and conducting improvement activities and projects, and the potential steps of reducing variation in key characteristics, and addressing variation management in design.

Analyze Products and Processes

Analyzing products and processes for improvement opportunities is the first step in implementing AQS. Its objective should be to gather and analyze data so that the most influential problems in the company can be spotlighted and targeted for improvement. The relative degree of process and product difficulties should be measurable, so that improvement efforts can be prioritized for the greatest impact.

Improvement Activities and Projects

After systematically analyzing their products and processes, suppliers will identify areas requiring improvement. The next step is to initiate and complete AQS improvement projects to accomplish the desired improvements. These improvements will usually require the disciplined use of structured problem solving, root cause analysis and corrective action.

Improvement activities and projects should be chosen based upon the business performance measures selected. The objective of the product and

process analysis is to identify opportunities for improvement that most affect those performance measures. Projects usually address three main issues: effectiveness, efficiency, and product design.

Reducing Variation in Key Characteristics

While analyzing processes and products and working improvement projects, suppliers will identify part and process characteristics where variation reduction will be highly beneficial to them or their customers. Product and process characteristics whose variation is particularly hurtful or costly are called key characteristics. Reducing the variation in these characteristics will lead to added economic value as well as improved quality.

Variation Management in Design

Suppliers often find that quality problems can best be confronted during the engineering design phase. Many manufacturing products and business processes are not capable of meeting minimum requirements even when they are operating at maximum effectiveness and efficiency. The fundamental cause is often found in the design of the product itself.

If the supplier has product design responsibility, the steps described in Section 4.5 of Addendum 1 should be applied during the product design phase to reduce variability. Regardless of whether the supplier has product design responsibility, they should work with Boeing Engineering and, when possible, Integrated Product Teams (IPTs) to discover more about customer and design needs. Such participation can help them take advantage of the benefits inherent in "designing in" quality. It also provides a setting where the supplier can communicate product design deficiencies to those who are responsible for the design.

Management review

Management, through frequent reviews, should seek to institutionalize the results of the improvement activities. They need to ensure that quality improvements are related to the performance measures, goals and success of the company.

Highlights

The principal elements of AQS are shown in figure 2.1. The supplier should have a continuous improvement system in place and have the ability to

- Identify useful performance measures related to cost, waste, defects, quality, cycle time, working capital, and customer satisfaction.

- Analyze products and processes and systematically identify the best places to put improvement emphasis and resources.

- Achieve permanent improvement through structured and scientifically sound improvement activities -- e.g., AQS projects, Six Sigma projects, Lean manufacturing activities, simple improvement activities.

- Understand the various CQI tools so the right tools can be used during the AQS improvement projects.

- Determine and measure the variation of key characteristics and processes, and demonstrate variation control and capability of key characteristics.

- Implement corrective action when a

  - Problem is found
  - Process or product needs improvement
  - Key characteristic is not in control or not capable.

  This corrective action consists of systematically identifying and controlling key sources of variation as well as identifying and institutionalizing solutions for problems through the AQS problem solving process (see figures 2.2 and 2.3).

- Sustain the improvement by instituting a control plan to monitor and regularly verify the performance of the improvement.

- Integrate quality- and value-enhancing improvements into the design of the product (for suppliers who have responsibility for product design).

- Direct all of the above through informed and involved management.

Years of experience in the use of AQS tools have demonstrated their value in improving manufacturing processes. Management should recognize that variation is as value destroying in business and transactional processes as it is in manufacturing and direct improvement activities in these areas as well.

Note: The section numbers in the following refer to Addendum 1 sections.

4. The Continuous Improvement System

Section 4.1.1 The supplier shall develop and document a continuous improvement system consistent with D6-82479.

Boeing expects that the following elements be incorporated into the continuous improvement system to ensure system effectiveness. Boeing experience shows that the following attributes are almost always present in effective continuous improvement systems.

- Knowledgeable people - Personnel responsible for the implementation of the continuous improvement system should be knowledgeable and experienced, and have the authority to carry out the necessary tasks. They should be adequate in number to ensure that the objectives are successfully accomplished. The continuous improvement system should be the primary responsibility for these people, not a secondary assignment.

- Involved management - Top management needs to be knowledgeable in the continuous improvement tools. They also need to establish the improvement system's overall effectiveness goals, and review the progress toward the objectives stated in the quality policy and the status of the established improvement goals. Management reviews should include the value received by both the company and its customers.

- Top-down strategic planning - Planning for continuous improvement should begin at the top of the organization and be flowed down in a strategic manner. Contract review should include the planning for resources needed both to achieve customer satisfaction and to meet the improvement system's requirements and established goals.

- Clearly defined and understood procedures - Improvement system procedures should be documented and available to responsible personnel.

- Corrective and preventive action system - A well-designed improvement system will contain a structured root cause analysis approach leading to robust, long-lasting corrective and preventive action.

- Lifelong learning - Training in the use of improvement tools to achieve established improvement objectives should be provided to all levels of involved personnel (including all levels of management). A method of proficiency testing for required learning should be documented and implemented where appropriate.

- Continuous improvement linked to value - Financial reviews of all improvement activities should be scheduled regularly to assess the costs and benefits of the activities and to redirect them, as necessary.

- Documentation of the continuous improvement process - Experience shows that some very good continuous improvement systems failed because they were dependent on one or two active individuals. When those individuals were promoted, transferred, or left the company, the system suffered or died because it did not constitute a way of life at the company.

- Link to business plan - The continuous improvement system needs to fit the long-term company goals as well as be consistent with the established quality and business systems.

- Effective internal audit program - The continuous improvement system must be validated periodically to assure that it is working properly. An effective internal audit of the system will point out needed preventive and corrective actions and ultimately provide that assurance.

5. Performance Measures

Section 4.1.2 The supplier shall develop performance measures such as waste, defects, cycle time, quality and customer satisfaction.

In order to improve, the supplier needs to measure business performance. Measurement allows management to make better decisions, identify areas needing improvement, allocate resources, control processes and ensure that customers are satisfied. Measurements help management understand where they are and whether they are making strides in achieving their goals.

A performance measure is a quantifiable assessment that provides a way of evaluating the condition, status, effectiveness or changes in business or work processes. Performance measures should include high-level business and economic measures as well as part and process measures (e.g. profit, costs and asset utilization, along with scrap, rework, cycle time and inventory).

The first and most meaningful measurements are linked to the company's bottom line and to customer satisfaction.

Managing Improvement Efforts

Business performance measures start from the top and are flowed down into the supplier's organizations. At each level, the measures need to be developed, monitored and managed. The supplier should concentrate on measures of both effectiveness and efficiency (see Identifying and Defining Performance Measures below).

A set of performance measures that capture customer satisfaction, the cost of waste and defects, flow time and quality are essential to understanding and managing the application and focus of the continuous improvement system.

An appropriate suite of performance measures will aid in managing the continuous improvement efforts by:

- Prioritizing potentially profitable project areas
- Monitoring project results continuously
- Assessing effectiveness of the CI program
- Allocating resources
- Deciding when to stop efforts on a specific project

Analysis and review of these measures should spotlight areas of the operation that are in need of improvement. It should also be possible to tie the continuous improvement activity resulting from Section 4.1.3 and the rest of Addendum 1 to improvement in the performance measures selected. Management should set challenging goals and spur actions that accelerate the desired performance.

Managing the Business

The performance measures should be chosen so management, the customer and all involved personnel understand them. <u>They should be used to manage the business.</u> Many measures chosen historically do not meet these criteria.

An appropriate collection of performance measures will help managers to:

- Allocate investment in physical capital
- Allocate resources for improvement in human capital
- Justify departmental expansion or contraction
- Understand customer desires
- Achieve customer satisfaction

Identifying and Defining Performance Measures

Measurement of improvement allows management to make better decisions, identify areas needing improvement, allocate resources and control

processes. Measurements help management understand where they are and whether they are making strides in achieving organization goals.

The purpose of performance measurement is to identify areas needing effort and to monitor progress.

Performance measures should reflect both effectiveness and efficiency.

Effectiveness

Effectiveness is measured through customer satisfaction, either internal or external.

External measures could include delivery timeliness, customer rejection rate, warranty costs, and product reliability.

Internal effectiveness measures could include first pass yield, rolled throughput yield, number of engineering changes, timeliness, product defects at any stage of the process, and amount of scrap, rework, reinspection, errors, mistakes, and flaws.

Efficiency

Efficiency is measured by the time and resources needed to produce a product, whether it is a physical product or the outcome of a business process.

Examples include cycle time, number of inspections/tests per day, amount of work in process, number of people or amount of time required to complete a specific paperwork process, excess inventory level ("Just in case" inventory) and costs per unit.

Both types of performance measures should have business and economic implications, and quality improvements should be translated into economic measures wherever possible. Of course, many quality improvements are not directly measurable (e.g., reputation, new business prospects, customer loyalty). Some improvement activities may be valuable to do from a business perspective and may be measurable, but it may not always be possible to link them directly to the bottom line (e.g., research and development spending).

The performance measures should be developed using a top-down approach. That is, high-level customer-oriented measures should be developed and flowed down into the organizations producing the work, with each level supporting the next higher level performance measure. The number of

measures at each level should be limited in number, so as not to overwhelm the improvement effort.

Features of a Performance Measure

Features of a performance measure include the following. Performance measures:

- Should initiate and determine subsequent action.
- Are linked with the quality mission, strategy, and actions
- Are communication tools for the people in the process, the customer, management, and line personnel
- Determine what gets done
- Exist at all levels of the organization, and are linked between levels: high level down through shop level
- Are customer centered
- Are associated with internal work processes that address cost and waste reduction, coordination, teaming, innovation and customer satisfaction
- Establish trends over time, not just snapshots
- Provide information about the *reasons* for a problem, thus supporting decision makers and problem solvers
- Expose non-productive improvement projects
- Contribute to direction, improvement and control

6. Process and Product Analysis for Continuous Improvement and Robust Design

Section 4.1.3 The supplier shall analyze its products and processes to identify and implement improvement actions to positively impact the performance measures of section 4.1.2. Due consideration shall be given to key characteristics and

the full range of process improvement tools in meeting this requirement.

6.1 Process and Product Analysis

A thorough analysis of the product and the associated processes should be performed using the tools described in D1-9000-1, AQS Tools. Some of the tools typically used include team brainstorming, flow charting the manufacturing process, collecting production data (e.g., defects, scrap and rework), collecting engineering information (e.g., specifications and drawing datums) and performing a risk analysis. Additionally, techniques such as Value Stream Mapping can be applied to assist in the correct identification and prioritization of improvement opportunities.

In addition, the tools can be used to solve problems and improve processes and products. For example, performing Pareto analyses of defects, scrap, rework or waste can highlight specific problem areas where quality improvement resources can be focused. Furthermore, the problem analyses can help identify whether quality problems are caused by mistakes (e.g., mismarked parts) or are due to excess variation. Many of the problem analysis tools can be used to reduce or eliminate both quality mistakes and variation.

6.2 Improvement Activities and Projects

Selecting Improvement Activities

After a systematic analysis of processes and products, the supplier identifies and prioritizes improvement activities and projects. The emphasis of these projects should be on improving processes that affect the company and its customers. Any improvements made should be reflected in the performance measures, including those identified through Section 4.1.2 of Addendum 1.

Properly constructed performance measures can sometimes lead directly to specific improvement projects. “Triggers” can also help identify improvement areas. Examples of triggers for improvement activities include the following:

Scrap
Rework
Reinspection
Defects/escapements
Repairs
Excessive flow time
Assembly problems
Late deliveries

Desire to improve product performance
Desire to avoid capital asset purchases due to low margins
Low productivity
Long setup time
Excessive travel
Product complexity
Desire for parts count reduction
Low first-pass yield
Desire to introduce new products
Excessive inventory
Excessive and undesired variation
Customer complaints
Poorly centered/located processes for key characteristics
Low process capabilities
Shortages
Field squawks
Bottlenecks
Excessive overtime
Inability to meet customer demand
Lack of design for manufacturability

Leveraging Results

As problems are solved and improvements made, the supplier will often find that the same or similar improvements can be made in other areas of the company. By leveraging improvements in a systematic manner, the value of improvements can be magnified.

Structured Approach

Improvement projects should follow a sound, structured approach. The usual “firefighting” method must be avoided. An analytic approach that leads to root causes of problems and permanent solutions must be established in its place. The corresponding intensified activity will, in the long run, reduce costs, improves quality and increase customer satisfaction.

A structured approach to working projects is found in figure 2.2. A more detailed step-by-step approach is found in figure 2.3. Well-structured methods such as Lean Manufacturing, AQS, and Six Sigma are examples of effective approaches to improvement.

Key Characteristics

The structured approach to process and product analysis usually results in the identification of product or process characteristics or process parameters whose variation is particularly harmful to the company or its customers. When this occurs, the supplier should label these characteristics or parameters as key and proceed according to Addendum 1, Sections 4.2 through 4.4.

Project Documentation

The supplier should record all relevant information regarding improvement opportunities and activities undertaken.

To help increase the probability of project success, every improvement team should follow a standard process such as is found in figures 2.2 and 2.3 and avoid firefighting and ad hoc problem solving. In addition, a standard format for management review should also be followed (see Section 7).

6.3 Key Characteristic Statistical Control

Section 4.2 Key Characteristic Process Control Planning

Section 4.2.1 AQS Control Plans, or equivalent, shall be developed when any of the following occur:

(1) Boeing defines a key characteristic or a key process parameter.
(2) Analysis performed in 4.1.3 indicates that key characteristics are required.
(3) Lower level key characteristics are required to control variation of higher level key characteristics.

Definitions:

Key characteristics are attributes or features (dimensions, specifications) of a material, part, assembly, installation, or system whose variation has a significant influence on fit, performance, service life or manufacturability.

A key process parameter is a process input that is controllable and that has a high statistical correlation with the variation in a key characteristic.

Key characteristics are not just features that are important. They are features where **variation** is hurtful or costly.

Key characteristics and key process parameters apply to business processes as well as manufacturing processes.

For a further description of key characteristics and associated methods for identifying key characteristics, see the Key Characteristics section of D1-9000-1.

Both Boeing and the supplier can identify key characteristics and key process parameters. Boeing identifies key characteristics to aid in product assembly, performance or service life. The supplier may identify key characteristics for the same reasons, but they may also identify key characteristics to aid producibility and productivity -- that is, to help reduce internal waste, assembly time, labor, cycle time, inventory, and so on (see requirement 4.1.3).

An example AQS Control Plan is shown in Figure 6.3.1. The AQS Control Plan is a form used for documenting relevant AQS information on parts and processes. The first major category includes information regarding key characteristics and key process parameters, followed by information regarding the control of variation, process capability, gage information and sources of process variation. It should be updated as necessary (see the AQS Control Plan section in D1-9000-1, AQS Tools.) The AQS Control Plan includes a basic measurement plan. Suppliers may use the AQS Control Plan or an equivalent format that contains the same information.

Boeing
Advanced Quality System - Control Plan

Key Characteristic				**Control Method**	**SPC**		**Capa-bility**	**Gage Variation**		**Variation Sources**	
Name	Location	Measurement		☐ SPC ☐ Other (describe)	Type of Chart	Sub-group Size	Cpk	Type/ model	Capa-bility	Key Process Parameters	Settings / Control Methods
		When (in the process)	How Often								

Part/Process Name _____ Team Leader _____ Date (orig) _____
Part/Process Number _____ Company Name _____ Revision Number _____
Used-on Part Number _____ Revision Date _____

BOEING

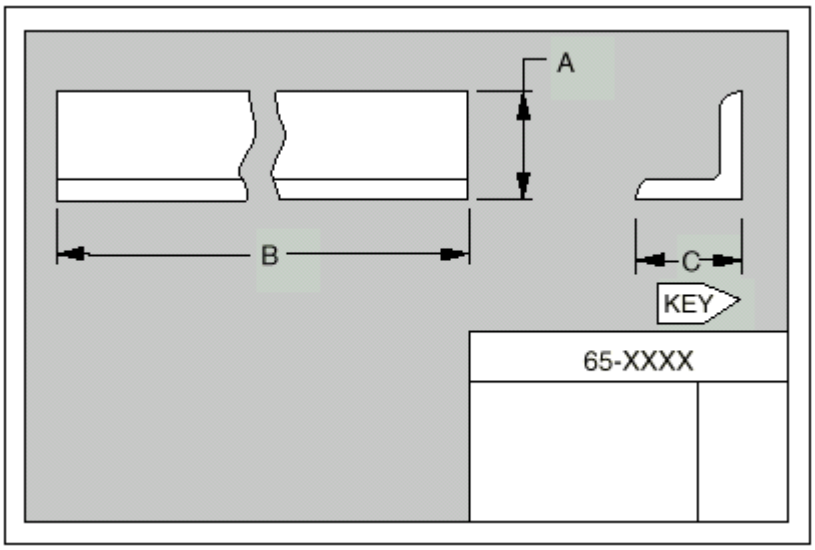
Advanced Quality System — Control Plan

Page____of_____

KEY CHARACTERISTIC							GAGE VARIATION		PROCESS VARIATION				
KEY Characteristic	Engineering Specification	Process step where measurement taken	Control Chart Used	Sample Size	Sampling Frequency	Initial Cpk	Type, make, and model of gage	Gage Capability	Process Step & Operation Number	Key Process Parameters	Process Parameter Settings	Control Method	DOE ?
Lower edge trim (Waterline)	0.500 ±0.005	after routing # 120	$\overline{X}$-R	5	2 per shift	0.84	height gage, Fowler, T17-X	0.0017 (16.6%)	Routing # 120	• router speed • cut depth	• 2000 rpm • 0.250 in	• machine setting • tool aid	YES

When key characteristics or key process parameters are provided by Boeing, they will be noted directly on appropriate documentation, such as the face of the drawing, specification control drawing (SCD), engineering standard, process control document (PCD), purchase contract, or CAD/CAM digital definition. Key characteristics will usually be identified by the symbol **KEY** .

Key characteristics or key process parameters identified by Boeing or the



supplier, along with their engineering specifications (engineering requirements such as process parameters or dimensional specifications), must be recorded on the AQS Control Plan, or equivalent, or the manufacturing plan.

If a key characteristic is not readily measurable within the production setting (e.g., mean time to failure, leakage or vibration test results), the supplier should identify lower level key characteristics that influence that key characteristic. When measured and controlled, the lower level key characteristics should ensure that the top-level key characteristic meets Boeing requirements.

In addition, the supplier may find it valuable to flow high level key characteristics down to lower level key characteristics in order to reduce variation or improve quality or producibility in both the lower level processes and the high level key characteristic.

The information in the AQS Control Plan should also serve as the basis for a process database. A major goal of this database is the compilation of process knowledge that can be used to conduct quality planning in advance of production and to leverage the results. This knowledge will allow manufacturers to build products right the first time by matching part characteristics to machines or production processes. Design engineering can also use process capability data to create designs that are more robust to manufacturing variation.

Section 4.2.2 Variation control and reduction activities must be performed on identified key characteristics. The approved variation control method for a key characteristic is statistical process control. Methods other than statistical process control may be used, but measurable evidence must verify that the process remains statistically stable and capable with a Cpk exceeding 1.33. Other comparable process capability index measures may be used.

When variation is a problem, the root causes of the variation need to be identified and removed. Identification of key characteristics or key process parameters is the first step in variation reduction activities. When key characteristics are identified, some method of variation control must be applied to them.

Under most circumstances, a statistical control chart will be the most effective method to monitor and control variation. However, innovative use of tool designs, product designs, process design and mistake proofing can also help control variation. The goal is to reduce the variation of the key characteristic so as to reduce the costs associated with that variation. The method of variation control must be documented in the AQS Control Plan.

Regardless of the method chosen for variation control, measurements should show that the method does control variation in the process and should provide assurance that the process is repeatable and error-free.

If methods of control other than statistical control charts are used, then once stability and capability are established, measurement should still be made periodically to ensure that stability and capability have been retained.

The measurement system that provides the data should also be suitable for the measurements taken. A variation study to determine the capability and repeatability of the measurement system, including both the gage and the users, should be performed to ensure that the variation in the measurements is due mostly to variation in the part and not in the measurement process itself. The percent tolerance consumed by the measurement system should be in the neighborhood of 10%, and certainly no more than 30%. The gage should also be selected to yield adequate measurement resolution.

Methods of Variation Control of Key Characteristics

The following is a selection of tools that might be used to control variation on a key characteristic. Details on applying these tools are found in D1-9000-1, AQS Tools.

Statistical process control

Statistical process control (SPC) is a systematic method for measuring, graphing, tracking, and managing variation.

The use of statistical process control charts and the indicated actions taken help ensure that special causes of variation are identified and eliminated and that the process is stable and predictable. Statistical control charts are an important tool to help the user identify when a process has changed.

Capability analyses, along with statistical control charts, help ensure that the process is consistently producing product close to target with minimum variability. Capability analyses can, after a process is stabilized, reduce common cause variation so products not only meet engineering specifications, but also attain a level of minimum variation that is economically beneficial. Tools to reduce common cause variation include brainstorming, cause and effect diagramming, structure tree diagramming, DOE, process flowcharting and redesign, and problem solving – see D1-9000-1, *AQS Tools*.

Note: Statistical process control charts in themselves do not control processes. They provide information so process owners can make process improvements.

Steps for doing SPC:

1. Determine the process steps where key characteristics are to be measured
2. Determine the type of data to be analyzed.
3. Select the appropriate control charts.
4. Select the control chart subgroup size and sampling frequency
5. Collect and plot process data
6. Calculate the appropriate control limits
7. Identify out-of-control points and take corrective action to eliminate the causes
8. Identify the major sources of variation present in the process and remove or reduce them
9. Calculate process capability indices
10. Continue to reduce variation, as needed

Tooling

Tooling can sometimes provide a method for ensuring consistent product and a statistically stable process. Measurements must be taken to demonstrate consistency and stability resulting from the use of tooling.

Two aspects of tool design and manufacture should be considered.

1) Tooling should be designed and built with the goal of minimizing variation at every stage of part manufacture. This goal often suggests minimizing variation within certain processes and reducing the amount of variation introduced by each tool. For example, there may be a need to:

- Reduce warping and twisting during process heating and cooling.
- Ensure adequacy and repeatability of locating features on tools.
- Control flexure during loading, building, or moving of the part.

2) It is important that tooling be designed and built to facilitate the collection of variables measurements for each key characteristic. Methods should be developed for indexing the part to the tool so that required key characteristic measurements can be easily obtained (see Section 6.6).

Standard Processes

A standard process is one that has been developed and documented to be consistently followed, and is considered the best current method. Implementing standard processes can be a powerful tool in reducing variation. A standard process description should include both machine settings and controls, and work methods. Without standard, repeatable processes, root cause identification is nearly impossible. Standard processes

are achieved through a combination of teaming, documentation, training, and measurement. Examples of methods to achieve standard processes are visual controls, product/process value stream analysis and mapping, setup reduction activities/procedures, optimizing manufacturing flows, obtaining input and agreement from cross-functional team members, and using "lessons learned" on similar products/processes.

Benefits of standard processes include less variation among employees, time savings, reduction in rework and scrap, better communication and the ability to readily detect abnormal events. Once verified by performance data, a standard process can be considered a reliable process.

Mistake Proofing

Mistake proofing is perhaps one of the simplest and most commonly used methods for controlling variation. The goal of mistake proofing is to make variation impossible to occur, usually through physical means. Examples of mistake proofing include color coding of parts and tools, tabs and slots on mating components, and other controls on size and orientation.

Benefits of mistake proofing include fewer rejections, higher quality and improved customer satisfaction. In addition, costs can be lowered through reduction in skills training, rework and scrap.

Summary

Key characteristics should be produced by a standard process and be controlled by a method that can ensure the product is close to target, is stable, has minimum variation, and meets the capability requirements.

Section 4.2.3 The selected variation control technique shall be documented on the AQS Control Plan, or equivalent.

For Boeing defined key characteristics, the requirement to control and reduce variation may be subject to an agreement as documented on the AQS Control Plan, or equivalent.

The AQS Control Plan provides for the documentation of the method of variation control for each key characteristic identified. If other methods are used, they should be noted on the AQS Control Plan and the results recorded.

As part of Section 4.2.1, the process step, control method used, subgroup size, and sampling frequency must be recorded on the AQS Control Plan, or equivalent, or manufacturing plan.

Note: Boeing reserves the right to require that statistical process control charts be used to control the variation of Boeing identified key characteristics,. Boeing engineering documentation typically takes precedence over other documents controlling part or process quality. However, Boeing may relieve the supplier of maintaining SPC charts on Boeing identified key characteristics where SPC can be shown to contribute little or nothing of value to the product.

If statistical process control is chosen as the method of control for the key characteristic in 4.2.2 above, the following requirements must be met:

Section 4.2.4 Key characteristic measurements shall be taken from the current production products, and shall represent the normal production output.

Control charts are designed to yield an accurate description of the process as it functions over time. To do this, only data that represents the current production output should be used. It is usually not necessary to measure and chart all (100%) of the production output, but products that are sampled must represent the entire output.

Section 4.2.5 Control limits shall be computed appropriately and the limits shall reflect the current process output. Statistical techniques that are used shall follow industry standard methods.

One of the purposes of statistical control charts is to answer the question "Has my process changed?" In other words, "Is my process stable and predictable?" Whether a process is in statistical control is determined directly from the control chart being used to monitor the key characteristic. All control charts define statistical limits for the natural (common cause) variation of a process. These limits are called control limits.

Control limits are calculated from the data in the process. Since these limits help answer the questions above, they must be computed correctly. Users should take great care in making control limit calculations, as they are affected by sampling rates, sample sizes, the way subgroup measurements

are chosen, independence of the measurements, and other factors. (See D1-9000-1 "Sampling".)

Note: Control limits are different from engineering specification limits. Statistical control and statistical capability are also to be viewed and treated separately, since they serve separate purposes. Mixing the two concepts leads to misinterpretation of process traits. See D1-9000-1, *AQS Tools*, for a thorough discussion of these topics.

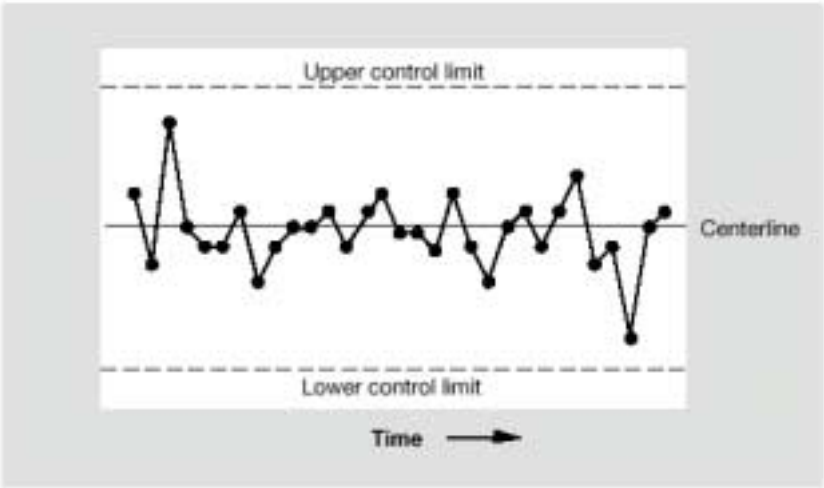


Figure 1.12.1

Initial Control Limits

Typically, at least 20 subgroups are needed in order to ensure stable control limits.

Formulas to construct control limits depend upon the control chart used, and are covered in D1-9000-1.

Measurements from different processes should not be combined on a single control chart (e.g., data from different production stations).

Recalculation of Control Limits

Control limits, to be effective, should be recalculated whenever a process has significantly changed, whether for the better or the worse. Reasons for the change should be investigated, known and recorded to ensure that the change is not just temporary. Failure to recalculate control limits means that the real intent of maintaining control charts is lost.

Section 4.2.6 When similar key characteristics from different products are combined on the same control charts (a part or product family or process output control approach), the characteristics shall have similar variability and shall be traceable back to the specific part or product.

When first developing key characteristics, AQS Control Plans and statistical control charts, a producer often places emphasis strictly on individual part key characteristics. This emphasis, if continued, can lead to maintaining a large collection of AQS Control Plans and control charts. Since it is the process that makes the product “good” or “bad”, limited benefit will be gained from monitoring and controlling only the product instead of the process. Often similar key characteristics can be combined on a single AQS Control Plan and control chart by identifying part groupings or by analyzing the same feature being produced by the same process on different parts. See D1-9000-1 for details on how to use process control to reduce the number of charts to be monitored, while retaining the integrity and diagnostic ability of the statistical process control charts that are maintained.

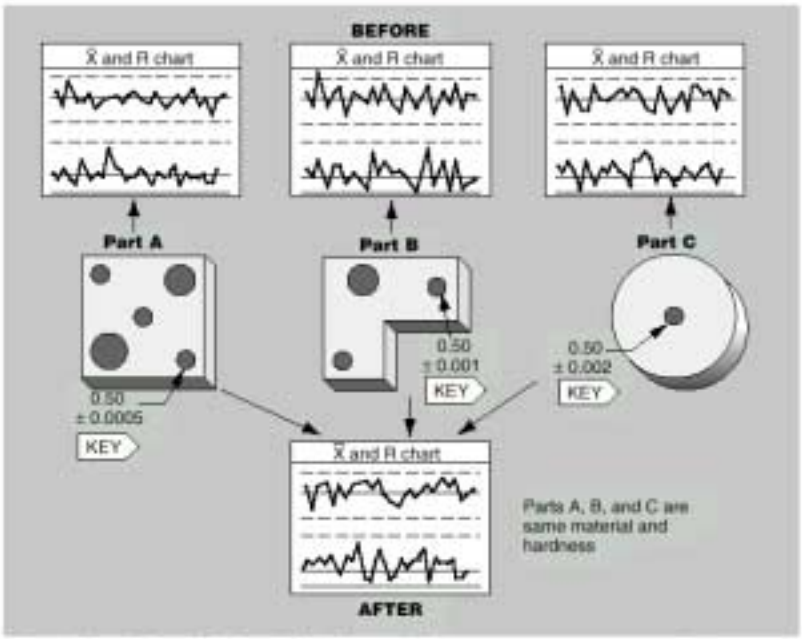


Figure 2.4.1. Parts A, B, and C before and after process output control

The purpose of a control chart is to monitor **a single** process. If the process being monitored is actually more than one process, valuable information regarding the processes will be lost. Control limits will not be calculated correctly and incorrect decisions will be made. For this reason, a statistical

test should confirm that parts combined on a single control chart exhibit similar variability.

6.4 Process Control, Capability and Variation Reduction

Section 4.3 Key Characteristic Process Control and Capability Requirements

Once key characteristics have been identified and documented, variation control and reduction techniques must be applied to those key characteristics.

Processes are optimized through reduction of both special and common cause variation. Statistical control charts are used to identify special causes of variation.

Measurement system analyses, cause and effect diagrams and statistically designed experiments are commonly used tools to identify and reduce common cause variation.

If statistical process control is chosen as the method of control for the key characteristic in 4.2.2 above, the following requirements must be met:

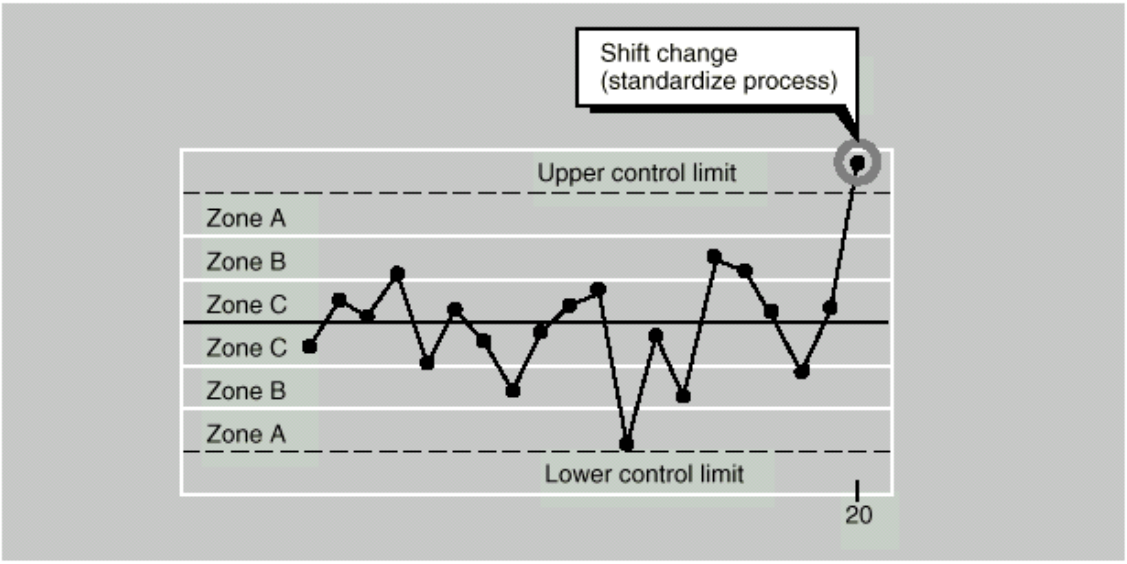
Section 4.3.1 When a key characteristic is not in statistical control, the out-of-control condition shall be investigated for special causes of variation, and corrective action taken to permanently remove or minimize special causes of variation.

A process is considered out of control when nonrandom behavior is present in the process. This behavior is evidenced on a control chart when nonrandom patterns occur (e.g., points beyond the control limits, cycles, trends or shifts). Points beyond the statistical control limits must be investigated for assignable causes of variation. (See D1-9000-1, *AQS Tools,* "*Interpretation of Control Charts"*).

If an out-of-control condition arises, the question “What has changed?” should be asked. A control chart tells where and when the change took place, but not why. If reasons can be assigned to these special causes of variation, then they can be designated as “assignable.”

Corrective action consists of identifying and modifying the activity, situation, or policy that is creating the out-of-control condition. Part of the power of control charts is in helping correct process instabilities in a timely fashion, before they result in defective products.

Though control charts do not really “control” processes, they are useful tools that provide an early warning that corrective action should be taken.



Remove assignable cause of variation

Samples corresponding to out-of-control plot points should be removed from the control limit calculations, but should remain on the chart itself.

Once the process is stable (and out-of-control points removed from the control limit calculations), the control limits should be set and not changed until the process changes significantly. New plot points are to be compared with the set control limits.

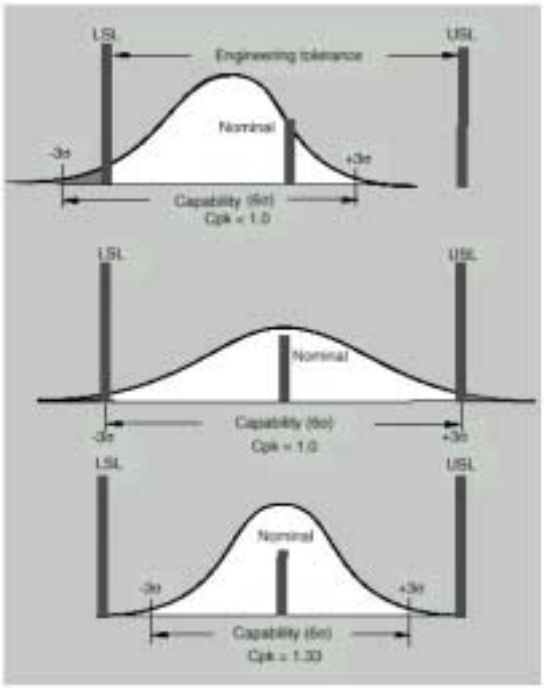
Section 4.3.2 Process capability shall be established for key characteristics monitored with control charts. A key characteristic is considered capable if its Cpk exceeds 1.33. Other comparable measures of process capability may be used.

Process capability indexes such as Cpk compare the natural or common cause variability of the process to the engineering specifications. These measures usually compare information about the variability of the process (usually measured by the standard deviation) and the process average to the target or nominal value desired and the engineering limits. Cpk, or other comparable indexes, can be used to evaluate the ability of a process to meet

the engineering specifications. Examples of comparable process capability indexes include Cpm, quality costs/loss and Z-scores (as used in Six Sigma programs).

The objective is to measure and reduce common cause variation in the process so the process produces output close to target with minimum variation.

Process Capability



See D1-9000-1, *AQS Tools*, Process Capability Analysis for further information regarding capability indexes and their calculation.

If attribute data is used, then capability is measured in terms of the defects per million opportunities (DPMO). To meet an equivalent Cpk of 1.33, the maximum DPMO is 66.

The key characteristic should be in statistical control before establishing the process capability. Otherwise, the process capability itself tends to be unstable.

Process capability indexes should be recorded on the AQS Control Plan (or equivalent) or in a process capability database. They should be available to Engineering at both the supplier and Boeing for designing new products and manufacturing processes.

Cpk or comparable measures of process capability should be recalculated whenever there is a significant process change. Recomputing Cpk should accompany the recalculation of control limits for the statistical control charts. Recalculating Cpk when there has been no substantial change in the process (e.g., a large change in variation or a process shift), and no change in the engineering specifications, will yield limited benefit and may drive unneeded actions and false security.

Section 4.3.3 If the key characteristic is not capable, the supplier shall identify and control sources of variation in the processes that are correlated with the key characteristic and take corrective action. D1-9000-1 contains information that is useful in diagnosing sources of variation as well as providing guidance in techniques to reduce measurement error and process variation.

In some cases, it may be impossible or prohibitively expensive to meet the requirements of 4.3.1 through 4.3.3. As such, the customer must approve any exceptions to paragraphs 4.3.1 through 4.3.3.

In addition to reduction of special causes of variation, the identification and removal or control of sources of variation inherent in the process (common cause variation) can help lead to a higher quality process.

Measurement Systems Analysis

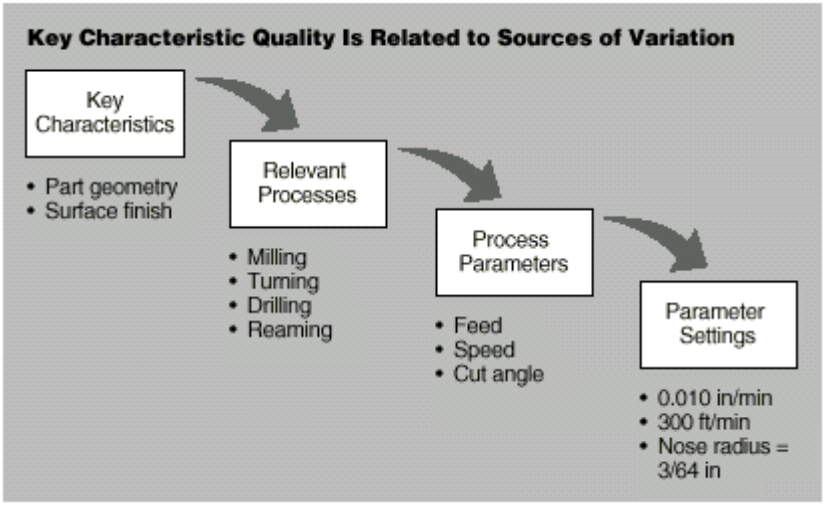
One of the most common sources of apparent process variation lies in the use of poor measurement systems, which include the devices used, fixtures, tooling or shop aids, and the training of the people doing the measurement. Poor measurement systems reduce the ability to demonstrate control or capability and make investigation into the sources of variation difficult. Therefore, investigations into measurement system variation are usually a good place to start. The repeatability and reproducibility of a gage should, in fact, be known prior to taking measurements on key features of products or processes.

Identifying Sources of Variation

Sources of common cause variation affecting the key characteristic can be found by investigating all of the processes that are relevant to the production of a key characteristic. Variation within these “relevant processes” is influenced by one or more variables and their settings. These variables and

settings are called “process parameters” and “parameter settings,” respectively.

Tools such as brainstorming, process flow charts, cause and effect diagrams and statistically designed experiments (DOE) can be used to systematically identify the processes and process parameters that contribute to variation in the key characteristic, along with the process parameter settings that help optimize the process. For further discussion of the tools available to help in this effort, see D1-9000-1 *AQS Tools* .



All efforts to identify sources of variation should be recorded.

Controls should be established to ensure that the key process parameters and their optimal settings change as little as possible.

Ultimately, the goal is to control processes through identifying settings for key process parameters that minimize variability in the process output. By controlling these process parameters it may be possible to reduce the measurement frequency of key characteristics on parts and processes.

Each key process parameter and its setting and the control methods used to monitor it should be recorded on the AQS Control Plan, or equivalent, or the manufacturing plan.

Section 4.4 Acceptance of Key Characteristics Based on Statistical Process Control (This section is required when using process data to accept product, but does not alleviate any engineering requirements mandating 100% inspection.)

When a process has been stabilized and meets the minimum capability requirement, the supplier may use this section to reduce the costs associated with inspection processes.

When statistical process control is used as a method for acceptance of the key characteristic, the following requirements shall be satisfied:

a. The process shall be in statistical control with variable data (using appropriate process control charts) before process capability is calculated.
b. The process shall be capable.
c. The process capability measure used to justify reduced inspection shall accurately represent the process fallout rate using industry standard statistical methods.
d. If the process ceases to be in statistical control, normal end-item sampling will resume for acceptance of the product feature until the cause has been identified, corrected and the process is back in statistical control and is capable.

Note: The Boeing representative must be notified of this process implementation prior to incorporation.

Process control and capability data may be used for in-process or final inspection of Boeing product. Product acceptance may be allowed for a characteristic produced by a stable and capable process. Non-standard methods are subject to Boeing approval. Refer to AS9100, Section 4.20.2.

Determine appropriate product acceptance actions, per the table below, by using the most recent point on the control chart and the process capability ratio (Cpk).

The most recent point indicates that the characteristic:	**Required Actions** Based on the Process Capability Ratio (Cpk)		
	Less than 1.33	1.33–1.67	Greater than 1.67
Is in control	100% inspection or approved acceptance sampling plan.	Accept product for the given characteristic.	
Has gone out of control. All measurements in the sample are within specification.	**Take Corrective Action**		
	100% inspection or approved acceptance sampling plan.	Inspect 100% since the last in-control point.	Accept product for the given characteristic.
Has gone out of control. One or more measurements in the sample are out of specification.	**Take Corrective Action**		
	100% inspection or approved acceptance sampling plan.	Inspect 100% since the last in-control point.	

*****NOTE: This Table applies only to arithmetic tolerances.**

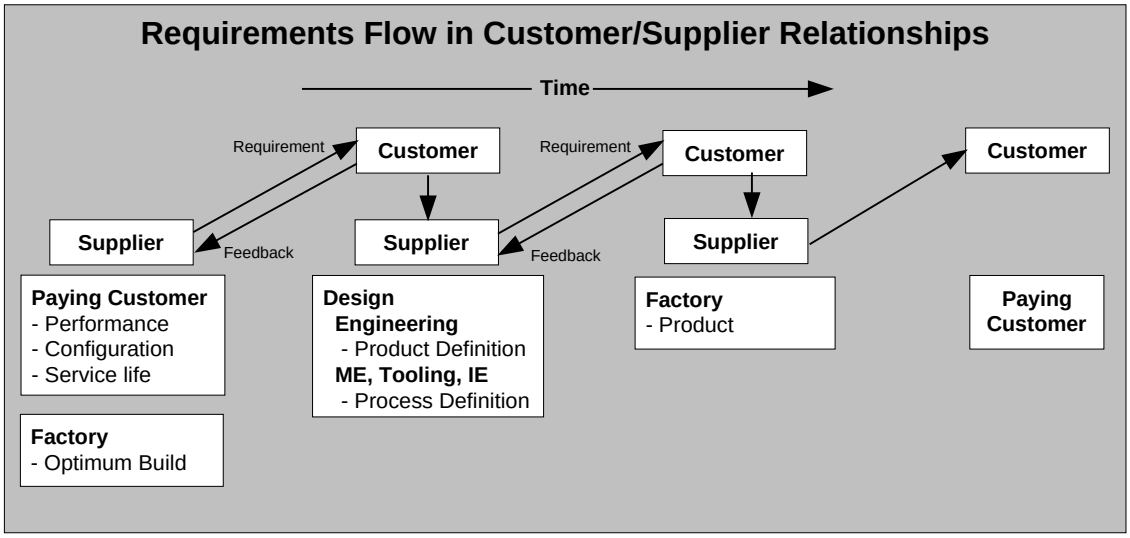
6.5 Variation Management in Design

Section 4.5.1 Variation management in design shall occur through customer/supplier efforts throughout the design process

The first aspect in this strategy for variation management is the establishment of a complete diagram of all customers and suppliers who need to be involved in addressing variation management in the design. The second aspect is the creation of a communication plan that involves all the customers and suppliers throughout the design process.

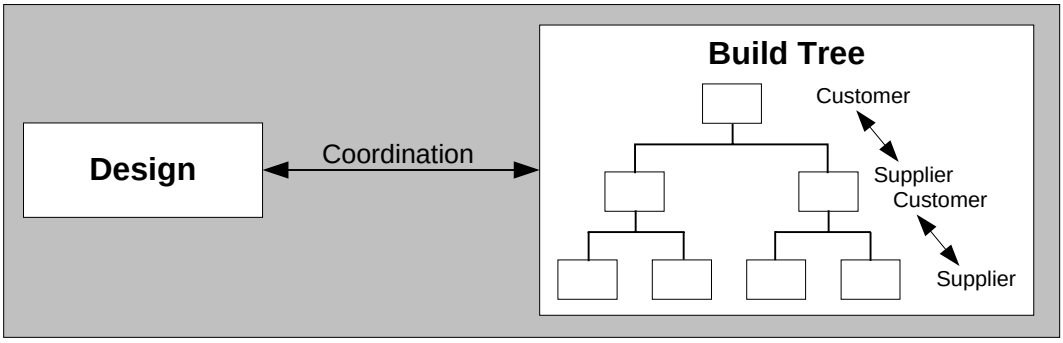
Customer/supplier relationships in all their forms are fundamental to quality systems, but especially important to the success of variation management in design. The infrastructure to be identified must include all the customers and suppliers. In manufacturing environments, customers and suppliers are generally thought to be just the people who receive the deliverable product and the people who deliver the products, respectively. In a typical design scenario, a “company” perspective may dominate. The design community

may wrongly think of their customer only as the company paying for the deliverable product. Likewise, the supplier might inappropriately be thought of only as a company supplying raw materials, detail parts or assemblies. This customer/supplier model is too limited to facilitate variation management in design effectively.



4.5.1_1

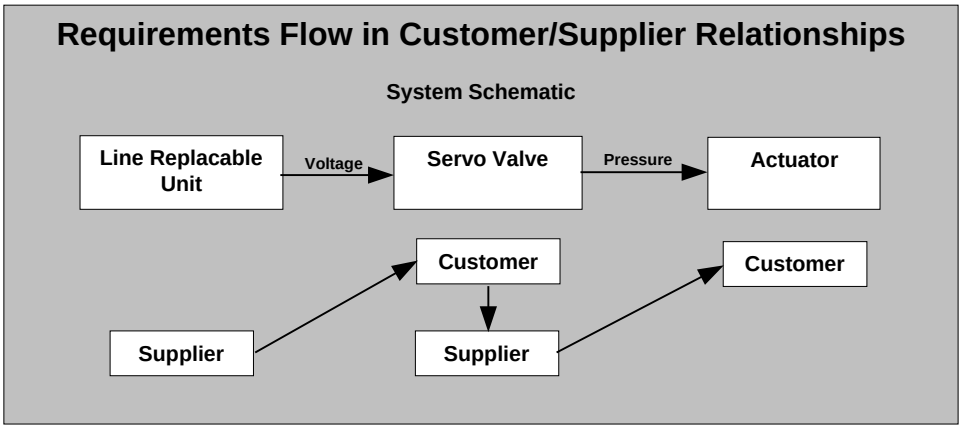
The design community must expand the customer definition to include not only the paying customer, but also the various factory positions that will be tasked with producing the design. Depending on the scope of the design, there may be multiple positions or locations at the paying customer's facility, your company's facility and those of your suppliers. The definition of a customer may also be further expanded depending on the design environment and the amount of the design a company is responsible for. If those responsible for the product definition (typically design engineers) are not co-located with those responsible for manufacturing process definition (e.g. manufacturing engineering, tooling engineering, industrial engineering), then manufacturing process definition personnel also need to be considered as customers. If one's focus is on only a portion of the overall design, other design teams or groups responsible for manufacturing process definition may also have to be considered as customers.



4.5.1_2

The definition of supplier must be similarly expanded. Design teams focusing on product and process design for a lower level have to be considered as suppliers, along with the factory build positions for those components. Consideration must be given to the design community and the factory at both the supplier and customer, because they all have requirements or feedback to share during the design process.

In systems design, there are additional sets of customer-supplier relationships that must be addressed. These relationships are analogous to the systems schematics. For example, if the result of a system is a function of voltage or hydraulic pressure as shown in the system diagram, then the voltage (or pressure) is a supplier and the system result (i.e., rudder motion) is a customer. Naturally, those responsible for the product and process definition of the components of the system must treat each other as customers and suppliers relative to the systems customer/supplier relationships.



4.5.1_4

The other aspect of this requirement is communication and coordination throughout the design process. A typical scenario today is for a customer to issue a design specification document and a contract for a product to a supplier who has experience with similar products. The customer may try to define every requirement for the finished product in the design specification document. The design team at the supplier then starts by attending periodic

design review meetings with the customer based on some pre-set contractually specified dates. This process can be a very hit and miss, and rarely delivers the best design to meet performance and cost targets.

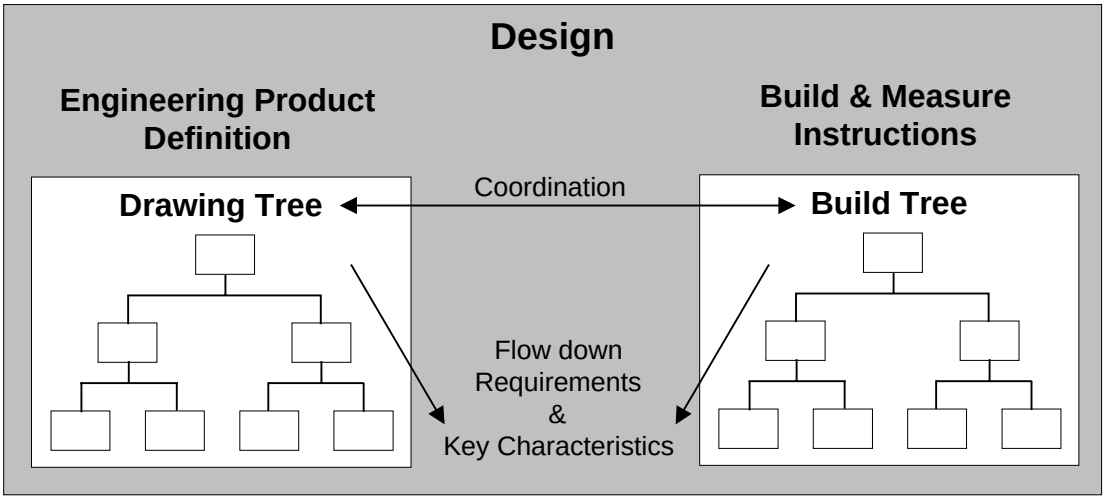
The best design solution will occur through continual communication between customers and suppliers. Suppliers generally have unique knowledge and experience that are critical to the best design solution. That knowledge and experience can affect the product and process design at all levels to positively influence performance and cost measures. On the other hand, customers generally hold critical knowledge about requirements that, when understood clearly, can ensure success in meeting the product and process design targets.

To meet this requirement, customers and suppliers are required to communicate and coordinate their product and process design information on a regular basis. The minimum requirement for a company is to meet this requirement only on contracts for products or processes for which this requirement is called out. But companies that use this concept more broadly will see the value of investing more time up front to gain a larger return later in the manufacture of products. The goal for companies is not just to meet the minimum requirement on certain strategic products and processes, but to use this concept on all the products and processes they design to reduce cost, cycle time and defects, while improving quality and product performance.

Section 4.5.2 Customer requirements shall be determined and key characteristics identified using a top down approach, beginning with a deliverable end item.

In almost every design requirement there is a variation-dependant attribute or key characteristic that must be identified and controlled, either by robust design or process control. It is critical that a process be put in place to obtain end item requirements from all potential customers, so that these variation-sensitive elements can be identified.

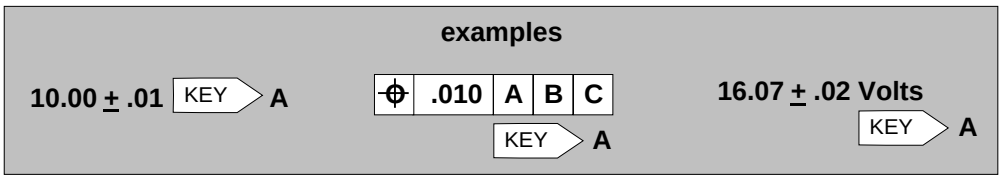
Obtained requirements must be translated to and documented in the product and process definitions. Where variation from nominal is deemed to have a major impact on a customer requirement, the affected attribute or feature is to be identified as a key characteristic in the product definition. Customer requirements and the resultant key characteristics must be flowed down to the level where they can best be addressed and controlled.



4.5.2_1

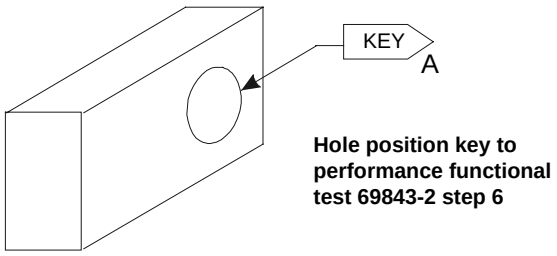
As “design” includes both engineering product definition and build (and measure) process instructions, key characteristics must also be noted and appropriately addressed in process documentation (see 4.5.6).

When key characteristics are identified, they are to be noted on product definition drawings/datasets/documents with a KEY flagnote symbol next to the feature or attribute. Next to the flagnote, a discrete alpha designator should be indicated.



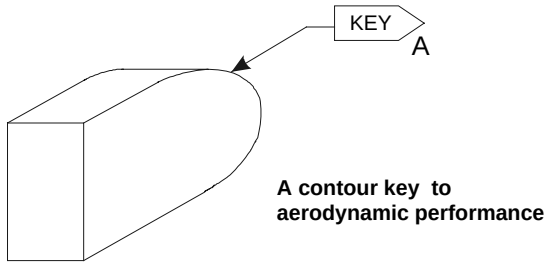
4.5.4_3

A note on the drawing, preferably on an isometric view, should indicate the key characteristic with a brief description of what it is and why it is important to fit, performance (function), service life or manufacturability.



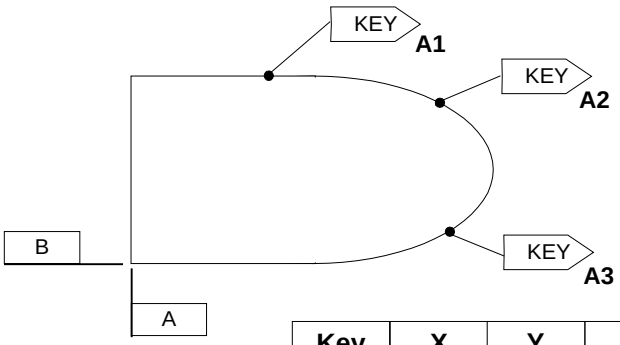
4.5.4_4

When a key characteristic is identified on a feature that can have numerous data collection points, such as contour or voltage vs. time, specific data collection points must be identified on the product definition. Enough points should be identified to represent the feature or to indicate the most important locations or time periods. Each point is to have discrete identifiers for data collection and coordination.



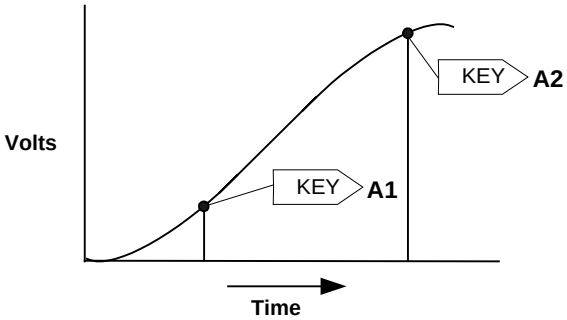
A contour key to aerodynamic performance

4.5.4_6



Key	X	Y	Z
A1	5.00	12.12	1.00
A2	16.03	8.06	1.00
A3	16.73	2.13	1.00

4.5.4_5



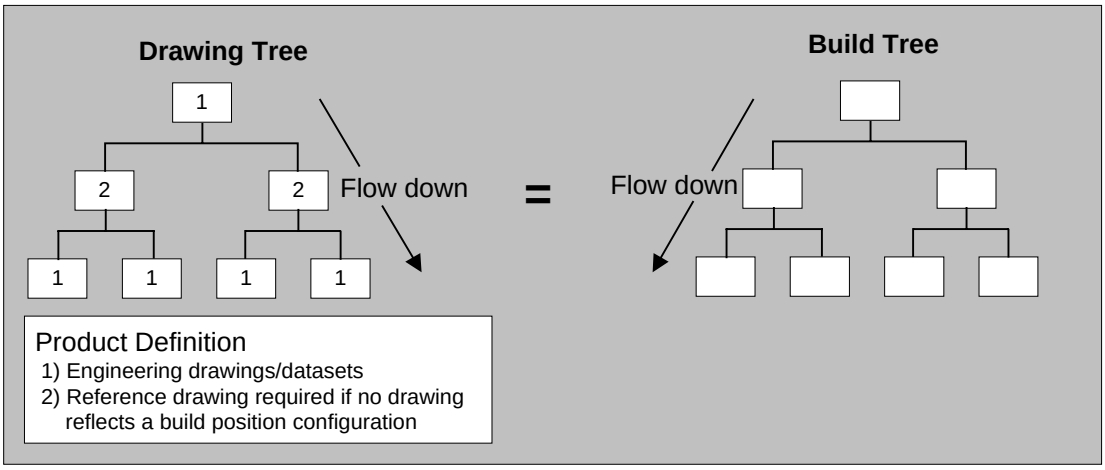
Key	Time	Volts
A1	5.00	12.12
A2	13.03	8.06

4.5.4_7

At a minimum, suppliers need to be able to demonstrate the correlation between the given requirements and the upper level design characteristics. The interpretation and flowdown of requirements should be presented to the customer for agreement prior to proceeding with the detailed design. World class suppliers will seek to remove barriers and work in a collaborative environment with their customers. The expected benefits are an improved understanding of the customer's requirements and measurable improvement in the cost and quality of the overall product and process design.

Section 4.5.3 The design (drawing tree) shall account for all stages of the fabrication and assembly process (build tree).

In order for the design to be robust to manufacturing realities, the drawing tree shall reflect all stages of fabrication, assembly and functional testing defined in the build process (build tree). Following this methodology ensures that all customer requirements and key characteristics (see 4.5.2) can be adequately flowed down through the complete product and process definition. The methodology also results in datums and tolerances (see 4.5.4) that can be documented for manufacturing, measurement and inspection. Finally, defining each stage of the fabrication and assembly process supports the generation of proper manufacturing instructions and minimizes the variation in the outcome of the process.



4.5.3_1

In the cases where it is not possible to have a drawing (or dataset) that matches each element of the build tree (build position), a reference drawing should be prepared to collect all the parts of that build position. This reference drawing should include functional datums, tolerances, and testing requirements (see 4.5.4 and 4.5.5). In larger projects, data may need to be collected from several design groups. If both structural and systems

components are assembled together in the same build position, the groups feeding that build position should work together to create the reference drawing.

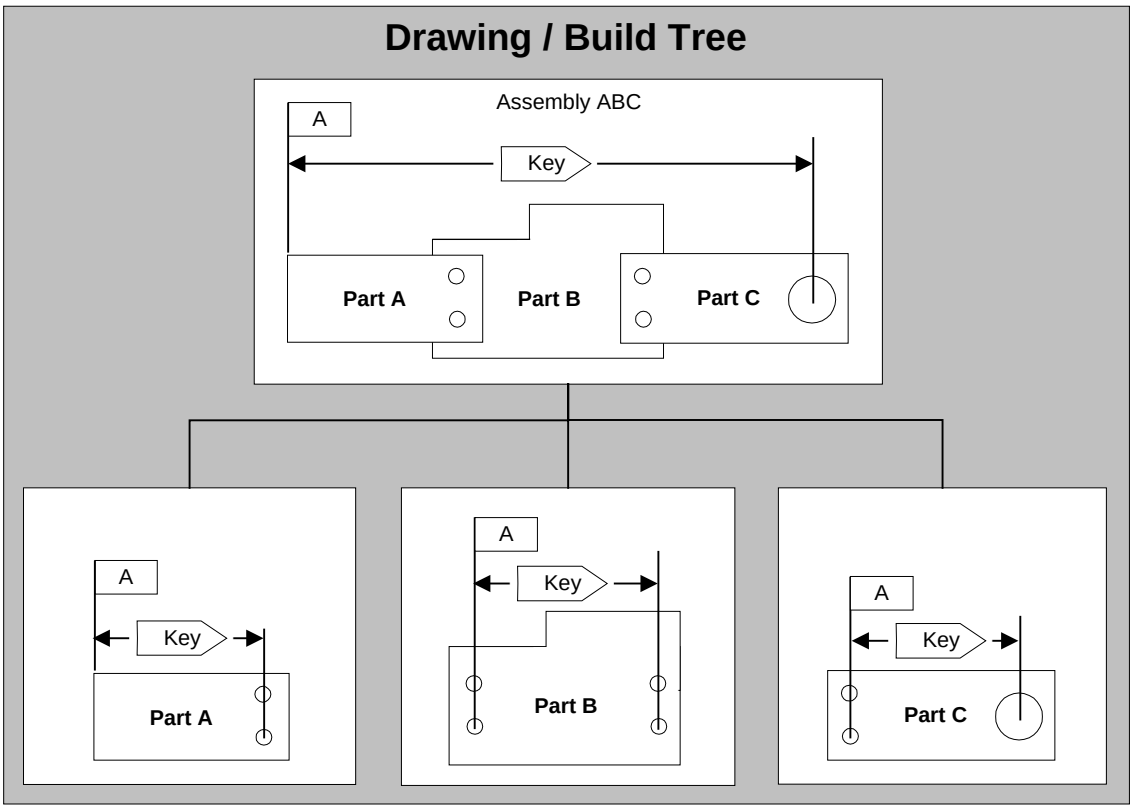
The minimum requirement is for the drawing tree and build tree to match. World class suppliers focus on the process that ensures that the two trees do match. The goal is to avoid having to rework the drawing tree after the fact, in order to make it match the build tree. Whatever process is developed, it should result in concurrent design and build definition.

Section 4.5.4 Reference points (datums) on the product design shall account for the way the product is fabricated, assembled, used, or functionally tested.

Previous paragraphs (4.5.1, 4.5.2 and 4.5.3) discussed customer/supplier relationships, flowdown of requirements and coordination of the drawings with the build process. Paragraph 4.5.4 supplements these requirements with a requirement for logical design datums. There are two important elements in meeting this requirement.

The first element is that of matching the datums of the product in a specific build position to the corresponding manufacturing indexes (part-to-part and part-to-tool). This concept, known as functional datuming, may seem very basic, but it is often violated. When this concept is violated, tolerances stack up and the variation monitored at the build position will not match that experienced by the customer of the product. Much time can be wasted improving product characteristics defined on the drawing that have no bearing on the quality of the product passed on to the customer.

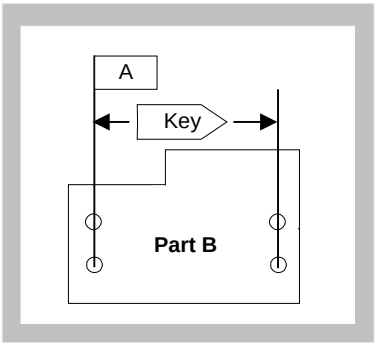
The second element of the requirement is that the datums be related to functional manufacturing features that flow down through the drawing/build trees. Ideally, using the same feature throughout the flowdown from installation through assembly to detail would ensure this. But as each assembly and detail part is split off in lower levels of the drawing and build tree, different features have to be picked for the datums/indices. Therefore, in order to have functional flowdown of datums/indices, key characteristic features are used to connect datums.



4.5.4_1

The figure above illustrates the flowdown of requirements, datums and indices (in this case, part-to-part) and the use of key characteristics to functionally locate datums. Datum A /index on part A of Assembly ABC in the top build position flows down functionally to the datum A/index on detail part A in the lower left build position. But the functional datum of the assembly does not flow down to detail part B. Part B will have its own functional datum/ index, based on how the part is used in the assembly. The key characteristic on part A is the connection to functionally relate the two datums and is a feature that must be controlled to reduce variation in the assembly.

The functional datums concept extends to cover another problem caused by a common design/manufacturing practice. Typically, in the name of design for producibility, engineers volunteer or are pressured by the manufacturing shops to place datums on the surfaces of the part that will be indexed in the machine. Although this is convenient for the fabrication build position, it may not match the way the customer will use the product.



In the example of part B above, more than likely this part would be manufactured by indexing to one of the sides of the part and then the four holes drilled. However it must be designed (documented in product definition) and measured as shown to meet customer requirements, as measurements from the edge of the part to the holes are not important to the customer. This is a case where the requirement to define datums according to how the part is used overrides the requirement to define them as fabricated.

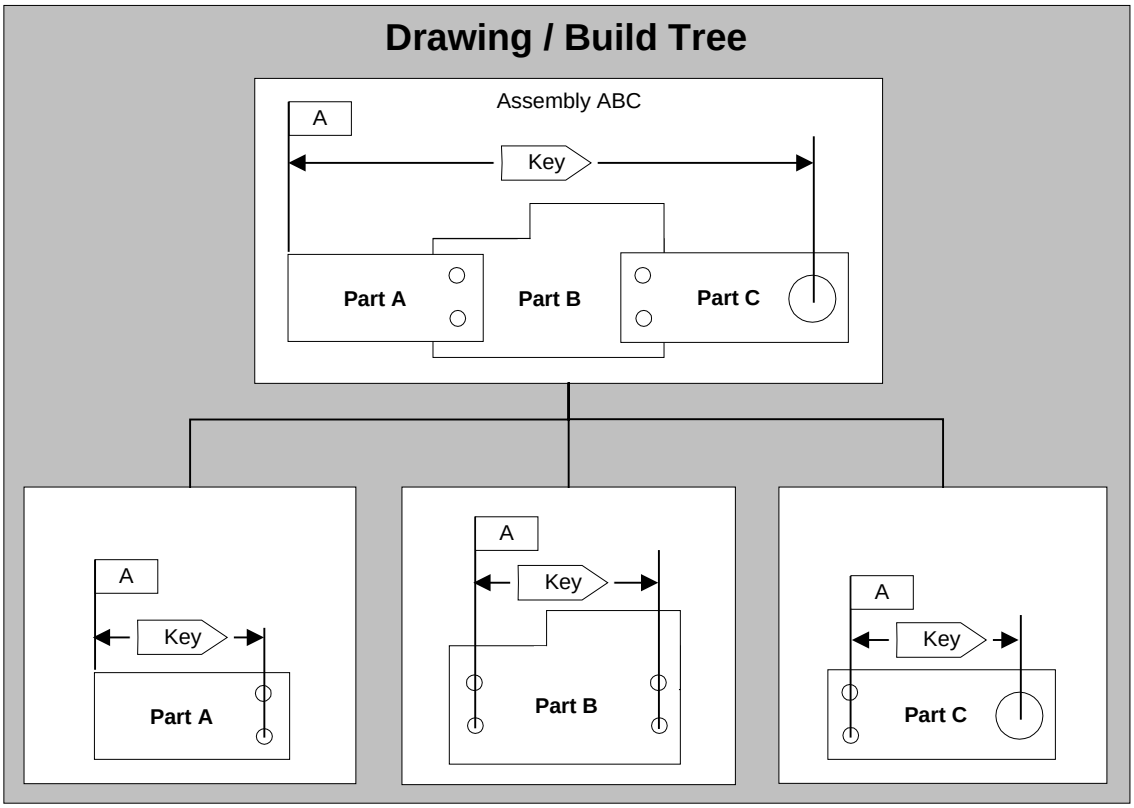
The requirement also refers to functional tests. Functional tests must be directly related to the system inputs and to the other upstream and downstream functional tests performed in the build tree. These relationships must be documented.

Section 4.5.5 Engineering tolerances shall be allocated to all levels of assemblies and detail parts to account for process capabilities.

The goal of this requirement is to take manufacturing process capabilities into account in order to achieve robust designs. Another popular industry concept called Design for Manufacturing and Assembly (DFMA) has this concept at its core. Under both concepts, designs that do not take process capabilities into account can inadvertently end up with tolerances defined that are tighter than the ability of the process. No amount of effort by the fabrication or assembly mechanics can overcome the problem. Defects, assembly problems and increased inspection will be unavoidable, and unit cost will end up higher than estimated.

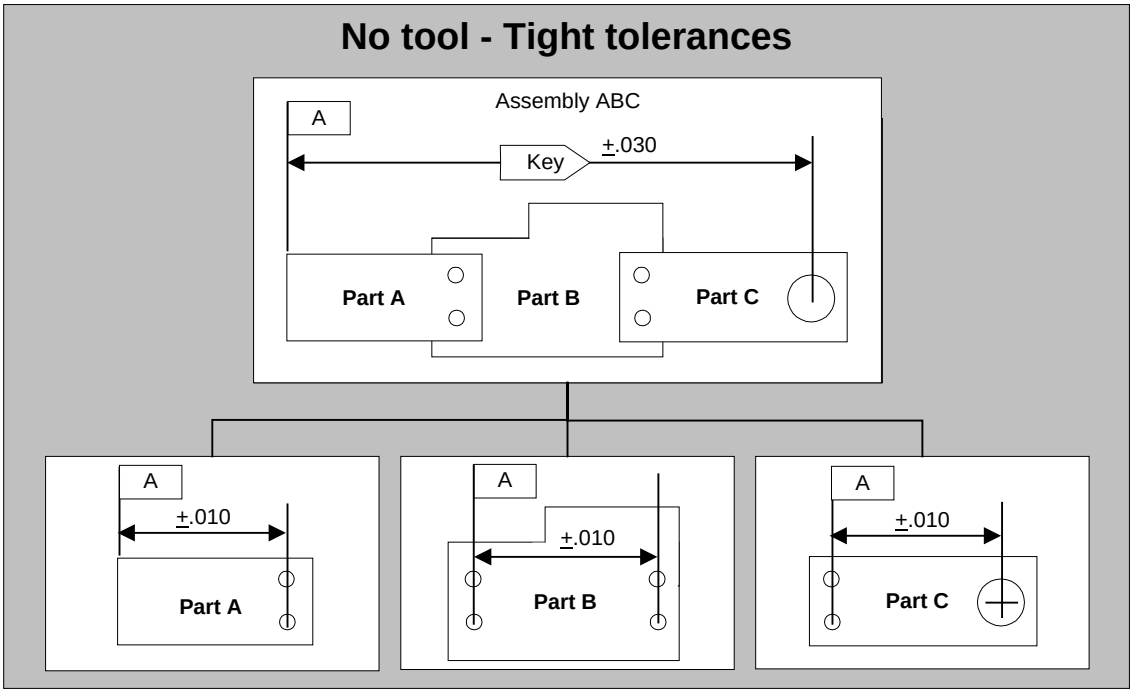
Requirement 4.5.3 helps ensure the design accounts for all stages of the build process. In executing this requirement, a manufacturing plan is generated at each level of build before the design can be made to match. Requirement 4.5.2 can help one use the build tree and manufacturing plans created by 4.5.3 to flow down the build and design requirements. Requirement 4.5.5 then comes into play as personnel in each affected build position review the requirements, associated tolerances and the ability to

economically achieve them. If requirements cannot be economically met, then a new manufacturing plan or a new design is required. Take, for example, the tree in the figure below.



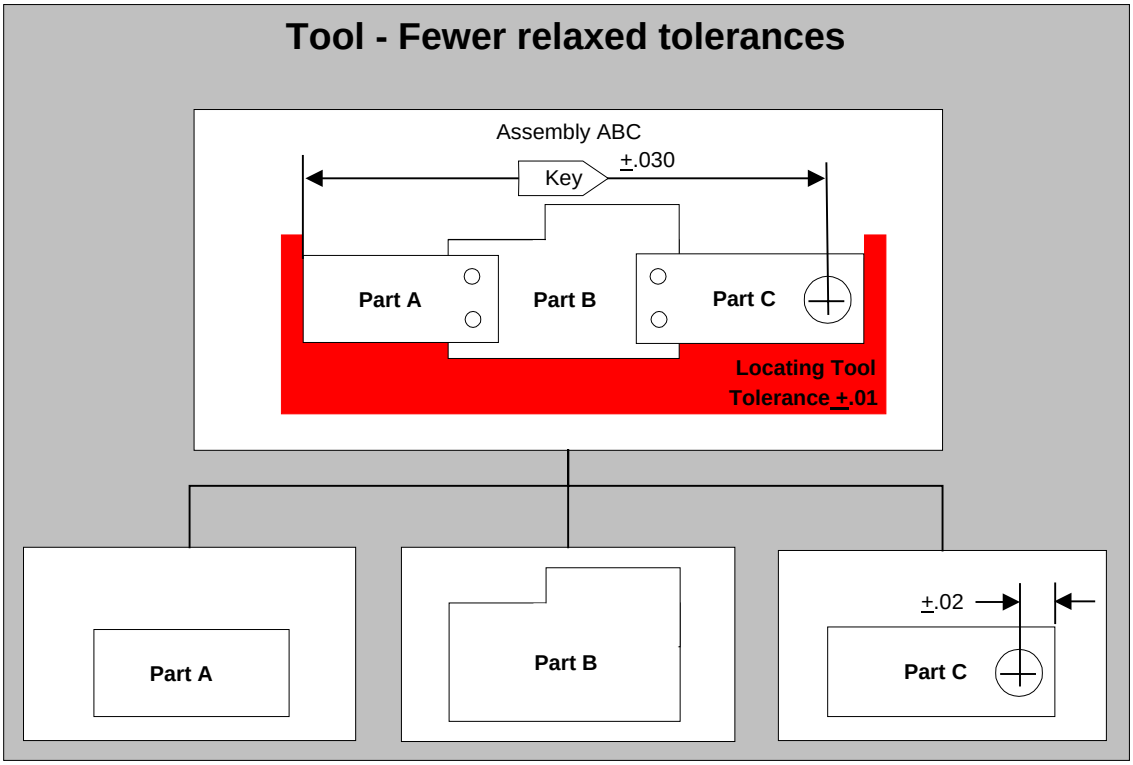
4.5.5_0

The key characteristic at the top carries a ±0.03 tolerance on it. In order to achieve this requirement efficiently at the assembly level, the requirement and the associated tolerance must be flowed down and allocated to the detail part characteristics correctly. But there are many manufacturing concepts that potentially could be used to meet the assembly requirement. The figures below depict different manufacturing concepts and how the tolerances might be allocated to meet this assembly requirement.



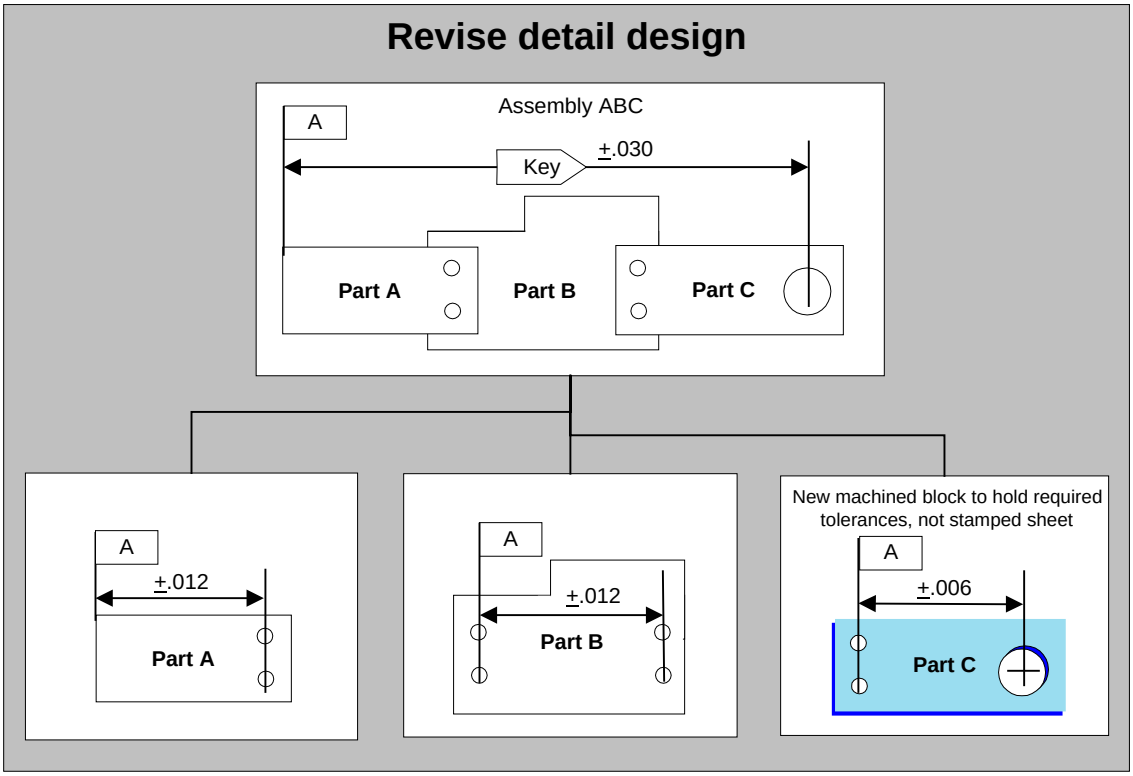
4.5.5_1

Figure 4.5.5_1 depicts the manufacturing trend to shift from part-to-tool manufacturing to part-to-part manufacturing in order to save the non-recurring and recurring costs of tooling. However, this approach requires tighter tolerances and higher detail costs. In the example above, the part profile may be stamped sheet metal, but the holes are put in using a more expensive process to hold the tighter tolerances. There are multiple ways to manufacture these details, but depending on the specific situation, the part fabrication costs may exceed the benefit of eliminating the traditional assembly tooling.



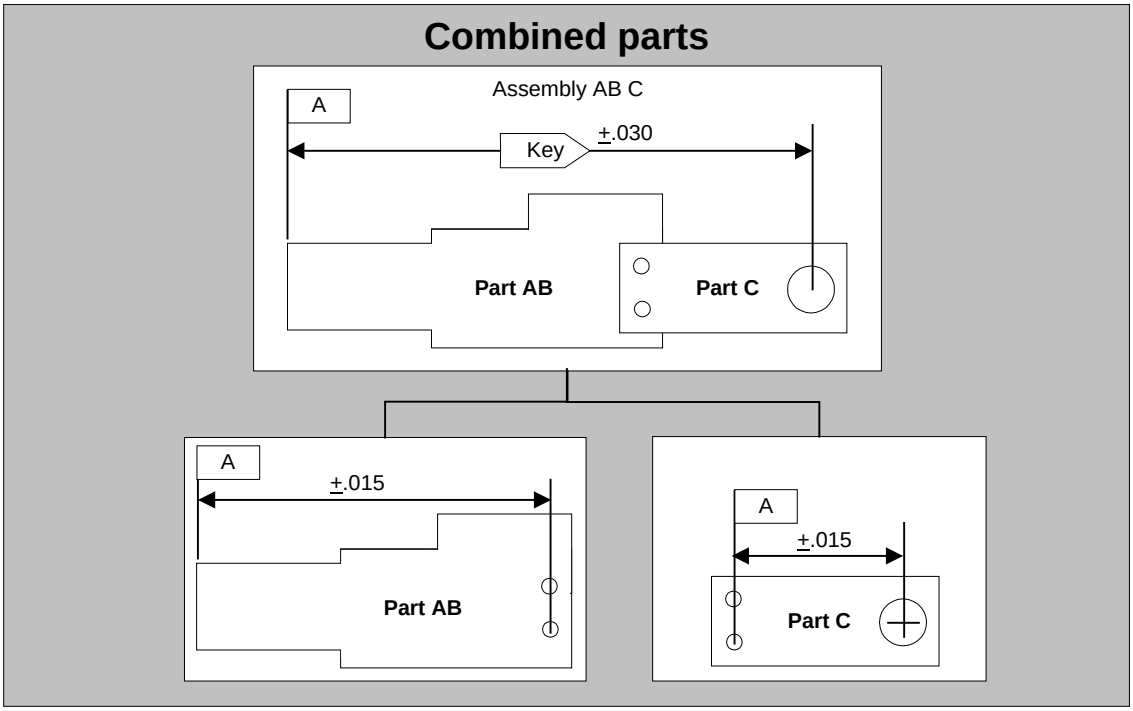
4.5.5_2

Figure 4.5.5_2 depicts a more traditional manufacturing approach using an assembly tool. Only one detail is directly involved in achieving the top-level assembly requirement. Through use of the tool, the tolerances on the detail part are allowed to be more relaxed, but the tooling tolerance cannot be ignored in the flowdown. And of course, the recurring and non-recurring tooling costs have to be accounted for in the cost of achieving the assembly requirements.



4.5.5_3a

Figure 4.5.5_3 shows a slightly different approach from the approach in Figure 4.5.5_1. In this approach, rather than using two processes to make each part, the part C detail has been re-designed to call out a different manufacturing process. Thus, not all parts have the same tolerance. This approach could be used to take advantage of a supplier with good process capability while giving the other supplier(s) some relief, and still meet the assembly level requirements.



4.5.5_4a

Figure 4.5.5_4 depicts a design approach called monolithic design. In this approach, the re-design creates fewer but more complex parts. With fewer parts in the assembly, fewer features are involved in meeting the assembly level requirement. Thus, tolerances are allocated across fewer features and can be more relaxed.

In the above example, the only way to learn the optimal approach is to work with one's suppliers and ask the right questions. Involved suppliers must know their process capabilities, be able to establish tooling costs, and provide for economic and technical evaluation.

This section must be handled in concert with section 4.5.2 as customer requirements from the factory are identified. However, the other customer requirements of 4.5.2 (performance and service life) must also be addressed. Efforts to allocate tolerances to match process capability should be pursued to the greatest extent possible. In some rare cases, process capabilities will not be available that match the tolerances necessary to meet the customer requirements. When this happens the tolerances must still be driven by the customer requirements and not process capabilities. Actions will have to be undertaken to improve manufacturing processes or create new ones that meet the customer requirements.

Section 4.5.6 During the design activities, manufacturing instructions shall be developed to ensure a standardized manufacturing process.

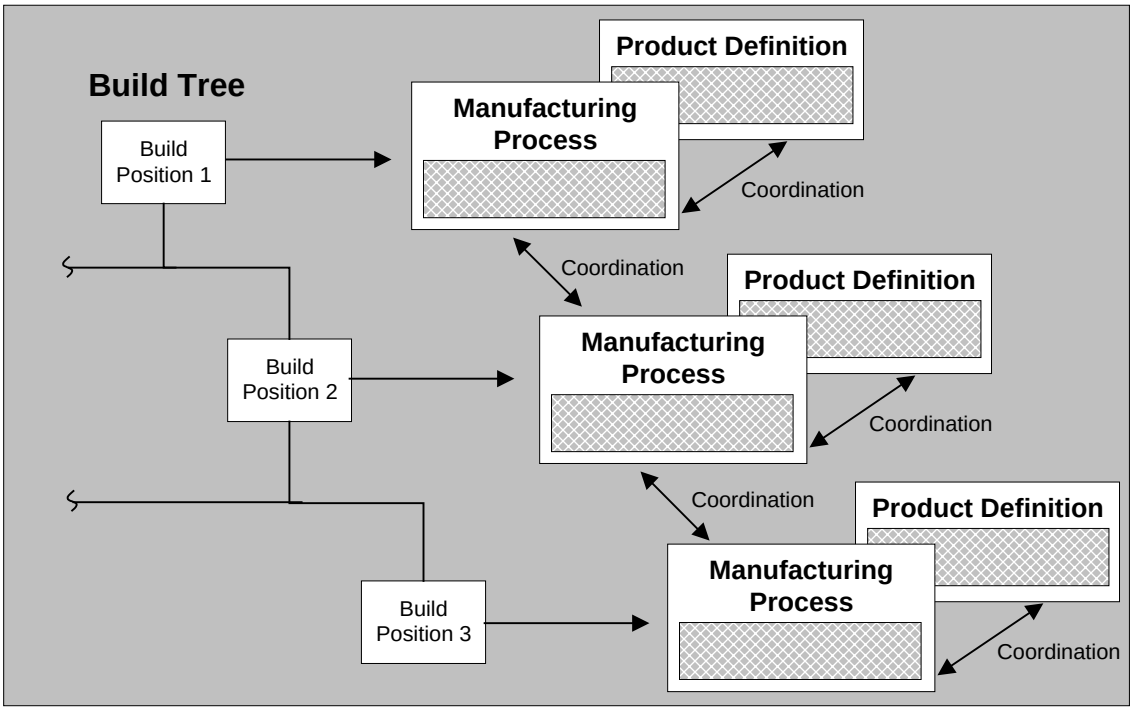
The previous sections focused on making the product definition as robust to variation as possible. The key to controlling variation in the factory is to follow a robust *process* consistently.

This requirement helps ensure that manufacturing instructions are robust by requiring that they be developed concurrently with design activities. The definition of design activities includes: product definition (engineering drawings/datasets), tooling design, facilities design, people and equipment certification requirements, equipment maintenance plans, manufacturing plans and measurement plans (including functional tests). All of the above must be included and coordinated in the product and process design to obtain consistent and cost efficient products that meet or exceed customer expectations.

The goal of having a standard manufacturing process is to minimize product variation due to interpretation in work instructions. If there is opportunity for multiple interpretations or flexibility in task sequences, then variation in the process results is almost a given.

Obtaining the optimum build process entails an interactive approach during the design phase and continuous improvement in the build phase. A recommended way to ensure standardization is to organize all build definitions relative to the build tree in one place, either in book or electronic form. At a minimum, the build definition for each build position on the build tree should include the process flow, manufacturing plan, tooling plan and measurement plan. Additional information that may be helpful includes: communication plans, training and certification plans, the product and process acceptance plan for the build position, and product transportation plans.

Communication plans are especially important for ensuring customer satisfaction and for working any non-conformances that may occur. Often the customer of a particular attribute is not the next build position but is several build positions away. This occurrence is especially prevalent in systems. Customers for each key characteristic should be identified in the measurement plan and the communication plan.



4.5.6_1

Once plans are integrated up and down the build tree, any changes made must be communicated to the product designers to ensure that the design and build processes remain integrated. Manufacturing instructions must evolve along with the product and process design to ensure that they reflect the integrated plan. Manufacturing instructions must also be defined to a level of detail that allows no interpretation in the sequence of tasks nor for tasks to be done in multiple ways.

The minimum requirement is that there be coordination and optimization of the manufacturing and product definition processes. The integrated product and process designs must then be translated into work instructions that accomplish the plan, provide the information to users in an understandable and accessible manner and allow no variation to creep into the product due to interpretation or vagueness. Suppliers who wish to progress beyond these minimum expectations will gain additional benefits by incorporating lessons learned from process standardization efforts elsewhere within their factories.

7. Management Review

Section 4.1.4 The supplier shall conduct periodic management reviews of these improvement activities, paying close attention to the effect on the performance measures, and modifying these activities as necessary.

One of the most critical aspects of AQS is that management be involved in continuous improvement and provide leadership for it. Although quality is actually built in by the process owners, it is essential for the achievement of lasting improvement to have strong, involved and committed executives who create the expectation and provide the leadership for continuous improvement.

An active management will have the following attributes:

- Focused on improvements, but tolerant of disappointing results
- Knowledgeable (and interested) about the details of improvement projects
- Knowledgeable of the various continuous improvement tools and their use
- Data- and fact-driven, using measurement systems that track both processes and outcomes
- Holds regular formal meetings on project progress
- Holds informal meetings with project members
- Integrates continuous improvement with “running the business”
- Has enough power to provide resources for new projects (including money, time, personnel, equipment, gages, etc.)
- Able to redirect or stop projects that are not yielding the proper expected results.

Management reviews provide a forum for setting direction, establishing and monitoring performance measures, anticipating problems and changes, applying facts and data, reviewing and directing improvement activities, prioritizing resources and breaking down obstacles to success.