



U.S. Department
of Transportation
Federal Aviation
Administration

Advisory Circular

Subject: Geometry and Dimensional
Considerations for Comparative Test and Analysis
for Turbine Engine and Auxiliary Power Unit
(APU) Replacement, and Repaired Parts

Date:
Initiated By: AIR-625

AC No: 33-12

1. **PURPOSE.**

This advisory circular (AC) provides guidance to support the development of technical data needed to show that an engine or APU replacement part complies with the airworthiness requirements under test and computation, per Title 14, Code of Federal Regulations (14 CFR) 21.303, using the comparative test and analysis approach. This guidance also supports the development of technical data needed for major repairs performed in accordance with 14 CFR Part 43.13(b), where parts fabrication and their implementation must be accomplished “in such a manner that the condition of the aircraft engine or appliance worked on will be at least equal to its original or properly altered condition.” This method supports showing the engine or APU still complies with the applicable airworthiness requirements of 14 CFR Part 33, and Technical Standard Order (TSO) C77.

This AC helps applicants identify potential dimensional differences caused by reverse-engineering parts using only measurements, and in doing so, aids the applicant in meeting the “stay within” criteria for comparative test and analysis methodologies. This AC does not provide guidance for projects that intentionally introduce dimensional differences into replacement parts or minor repairs.

2. **APPLICABILITY.**

- 2.1 The guidance in this AC is directed to parts manufacturer approval (PMA) or major repair applicants, Federal Aviation Administration (FAA) engine type certification engineers, and FAA designees.
- 2.2 This is a guidance document. Its content is not legally binding in its own right and will not be relied upon by the Department as a separate basis for affirmative enforcement action or other administrative penalty. Conformity with the guidance document is

voluntary only. Nonconformity will not affect rights and obligations under existing statutes and regulations.

- 2.3 The FAA will consider other means of demonstrating compliance that an applicant may elect to present. Terms such as “should,” “may,” and “must” are used only in the sense of ensuring the applicability of this particular method of compliance when the acceptable method of compliance in this document is used. If the FAA becomes aware of circumstances in which following this AC would not result in compliance with the applicable regulations, the FAA may require additional substantiation or design changes as a basis for finding compliance.
- 2.4 The material contained in this AC does not change or create any additional regulatory requirement, nor does it authorize changes in, or permit deviations from, existing regulatory requirements.

3. **RELATED READING MATERIAL.**

The following materials are referenced in this document. Unless otherwise indicated, you should use the current edition.

3.1 **14 CFR Regulations.**

- Part 33, *Airworthiness Standards: Aircraft Engines*.
- Section 21.303, *Application*.
- Section 43.13, *Performance rules (general)*.
- Section 43.15, *Additional performance rules for inspections*.

3.2 **FAA Publications.**

- AC 33-8, *Guidance for Parts Manufacturer Approval of Turbine Engine and Auxiliary Power Unit Parts under Test and Computation*.
- AC 33-9, *Developing Data for Major Repairs of Turbine Engine Parts*.
- AC 21.303-4, *Application for Parts Manufacturer Approval Via Tests and Computations or Identity*.
- AC 33.70-1, *Guidance Material for Aircraft Engine Life-Limited Parts Requirements*.

4. **BACKGROUND.**

- 4.1 The type certificate (TC) holder will often modify an industry standard or elect to create their own standard to comply with the airworthiness requirements established by the engine certification basis. The TC holder’s part designs are based on regulated engine requirements and known engine effects from variation in the part’s dimensional characteristics, material properties, and manufacturing processes. Further, part designs

evolve with engine specific experience and are produced and managed in a way that preserves compliance throughout the engine's lifecycle.

- 4.2 Relying solely on industry accepted standards to design, manufacture, and select materials for replacement parts, and for repairs that substantially remanufacture type design parts, may not result in the same level of confidence in the compliance showing as data developed during engine certification. Testing verifies that any assumptions used in a reverse engineering process about the adequacy of industry standards are correct. Testing also verifies if the measurement data is interpreted and applied correctly. This data can provide supporting evidence that shows the engine will likely continue to meet its certificated performance requirements with the replacement part or repaired part installed in the engine.
- 4.3 The FAA has observed significant variation in the way applicants define and substantiate the dimensional properties of replacement parts for turbine engines. This variation is typically caused by inconsistencies in the applicants' understanding of the type design part and how it functions in the engine. In some cases, reverse engineering procedures resulted in unintended dimensional differences in replacement parts that influenced the engine environment and the integrity of other parts in the engine. The differences were not detected before the effects of the differences were experienced in the fleet after the part entered service.
- 4.4 Unintended dimensional differences in replacement parts have resulted in engine configurations that were not compatible with the TC holder's Instructions for Continued Airworthiness (ICA). Sometimes unintended differences that are consequential to safety can result from imprecise evaluations of features that have a large effect on critical parts and engine systems. Sensitivities of interdependent parts are not an outcome of the FAA approval processes for replacement parts or major repairs. Under 14 CFR 21.303 and 33.75, applicants should know these sensitivities for developing suitable compliance plans that show functional equivalency and for conducting safety assessments so the project will have the oversight required by FAA approval processes. If these sensitivities are not recognized, the compliance plan might not detect important differences. Also, if differences are detected, but the sensitivities are not known, the compliance plan might need to include aspects of general compliance that will confirm these sensitivities.
- 4.5 Reverse engineering methods do not typically produce a design with the exact same dimensional characteristics as a type design part. This variance is because reverse engineering methods vary considerably in measurement techniques, how measurement data is interpreted and combined, and in dimensioning systems, all of which affect the dimensional similarity between type design and replacement parts. Conclusions about dimensional similarity without the comparative assessments that show equivalency is only valid when a single method is used to develop the dimensional properties of the type design and replacement parts.

- 4.6 Since applicants will not likely duplicate the TC holder's methods for measuring and dimensioning the type design part, dimensional differences in their replacement part can exist. Therefore, capturing the type design functional properties within the replacement part and safeguarding the interfacing parts and higher-level assemblies involves functional assessments that ensure the dimensional characteristics are equivalent. Depending on the extent to which the type design part supports the certificated performance of the engine, the functional assessments for the replacement part could involve both testing and analytical data that supplement the test. For example, to verify the full range of variation in a category 1 or 2 reverse-engineered part, testing could be used to cover a subset of the full range, and an analysis that is calibrated to the test data could be used to show functional equivalency through the full range of dimensional variation.
- 4.7 The applicant should provide compelling evidence that the replacement part is functionally equivalent to the type design part. Multiple FAA documents bring focus to the importance of staying within measurements taken from type design parts (unless substantiated) because dimensional similarity affects functional similarity. This AC helps applicants identify potential dimensional differences in reverse-engineered parts and meet the "stay within" criteria. The AC does this by providing examples for how dimensional differences might result from reverse engineering processes that use direct measurements taken from type design parts and encourages testing to verify similarity for what is not evident through direct measurement.
- 4.8 This AC does not provide guidance for projects that intentionally introduce dimensional differences into replacement parts or minor repairs. This AC helps applicants identify where unintended dimensional differences could exist in replacement parts and repairs and highlights the need to address them for the required compliance showing.

5. **GUIDANCE.**

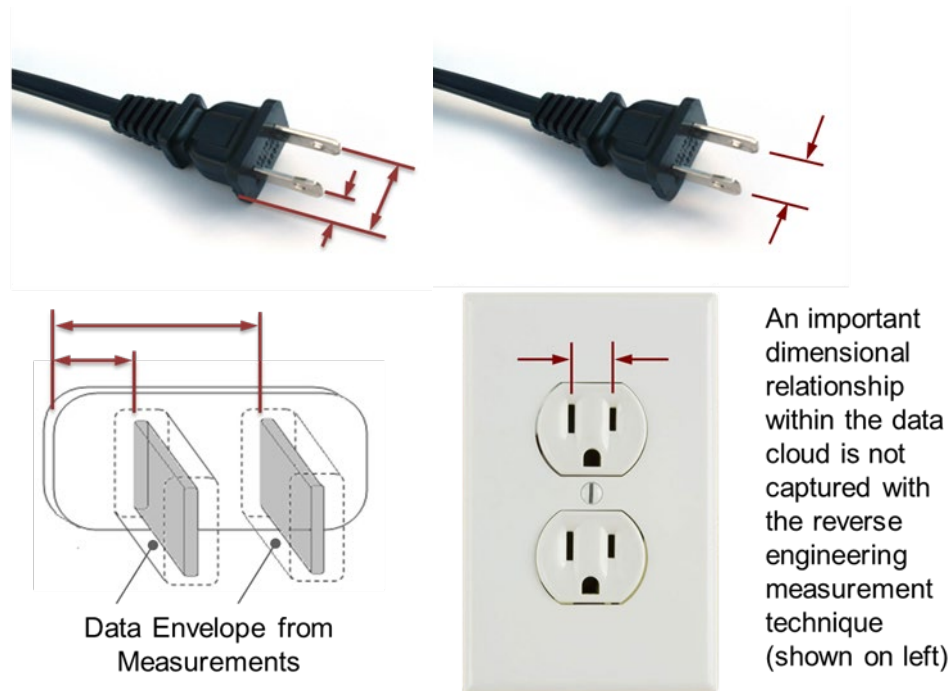
5.1 **Consideration for Dimensional Characteristics.**

This AC shows several considerations that can help applicants develop the dimensional characteristics for replacement parts and major repairs and enhance their showings of similarity. It also helps applicants reduce the potential for unintended dimensional differences in their part by drawing attention to what is not known about the type design part. The following discussions indicate where part-to-part bench assessments might not fully address the potential for dimensional differences to exist in the replacement part, and when a project could require a supplemental type certificate. Due to the wide range of reverse engineering techniques and manufacturing processes used by the industry, there could be other causes of dimensional variation that are not mentioned in this AC. The applicant should develop substantiation procedures that account for the possibility of these and all the other potential sources of dimensional variability that are applicable to their methods.

5.2 Geometric Relationships.

- 5.2.1 Some reverse engineering techniques generate a cloud of data from cumulative dimensional scans of multiple type design parts to determine the dimensional characteristics for their replacement part. However, assuming the replacement part shape can exist anywhere within the minimum, and maximum dimensional limits derived from measuring multiple type design parts might introduce unintended dimensional differences. For example, the type design could have dimensional requirements that maintain trends, positional dependencies, and relationships among interrelated part features within a data cloud. These relationships are not always obvious. Figure 1 provides an example showing the importance of recognizing the interrelated dimensions that affect the part's functional design.

Figure 1. Example of a Dimensional Relationship.



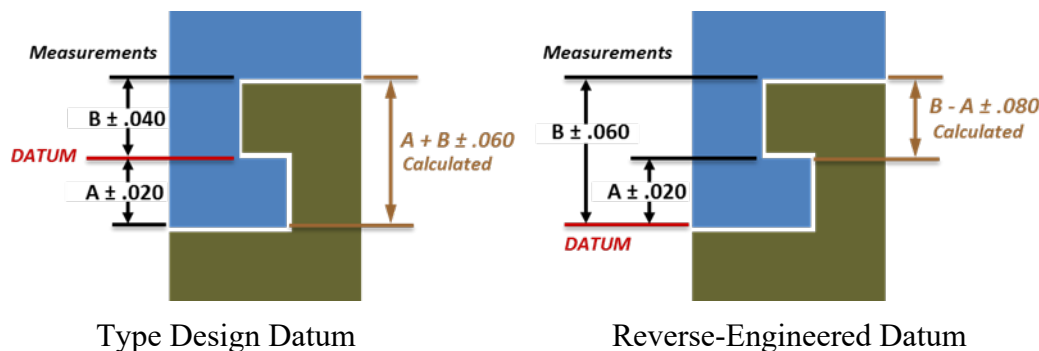
- 5.2.2 Similarly, if an applicant reverse-engineered a surface tolerance using only a minimum and maximum material condition without also controlling the surface transitions within the material envelope, the reverse-engineered surface may allow trends and step changes that are not present in the type design part. If the reverse-engineered dimensional characteristics allow these anomalies to exist in the surface of the replacement part, but they are not observed in the surface of the type design parts, then the criteria that characterize the reverse-engineered surface is not complete.

- 5.2.3 An understanding of how the part functions in the engine is fundamental to preserving the dimensional relationships intended by the original engine manufacturer. These relationships can influence the functional properties of the part and the integrity of associated critical parts. Therefore, reverse engineering criteria and measurement techniques that establish geometric relationships should reflect an understanding of the functional requirements of the part, and not be based solely on the total variation within a cloud of data.

5.3 Datum Selection and Reference Dimensions.

- 5.3.1 Datum selections influence the dimensional characteristics of a part. Datums are typically established based on how the part functions in the engine. Datums locate features on the part relative to other features and locate the part relative to other parts in the engine. Datums also ensure the part fits in the assembly and that it functions properly in the engine. Proper datum selection will take into account considerations, such as fit with adjacent hardware, function, and the state of the part while it is in operation.
- 5.3.2 Figure 2 shows how the selection of a datum can affect the interface between adjacent hardware. The figure on the left represents the type design, and the figure on the right represents a reverse engineering technique that places the datum in a location that could result in an interference fit with adjacent hardware.

Figure 2. Example of How Datum Selection Can Affect the Interface Between Parts.



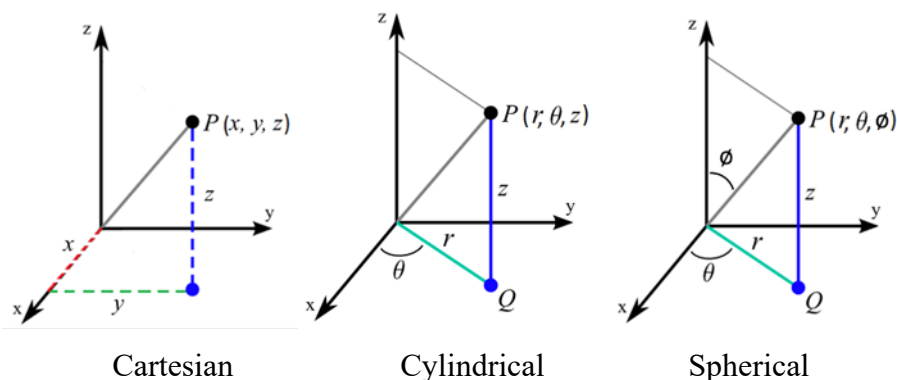
- 5.3.3 Reference dimensions are theoretical distances that locate features constrained by dimensions elsewhere on the part. They are usually calculated from a stack-up of many other dimensions and placed on the drawing solely for convenience. The accuracy of reference dimensions can affect the contours and transitions between features that support the proper function of the part. For example, reference dimensions could be used to check features that interface with critical hardware during the production process; therefore, an inaccurate reference dimension can adversely affect safety.

- 5.3.4 Placing pin gauges on external surfaces of the part to establish datums will not necessarily result in a part with the same functional design. Though TC holders sometimes use pin gauges to qualify used or repaired type design parts, pin gauges do not provide enough information to reverse engineer a part. A pin gauge contacts a particular location on several surfaces and averages the variation of the surfaces touched by the gauge. This technique does not provide any insight into tolerances, tolerance controls, datums, reference dimensions, or coordinate systems that the TC holder used to define the dimensional attributes of the individual surfaces touched by the pin gauge. Depending on how the applicant uses these measurement data for reverse engineering, this technique can create a different datum system for the replacement part that decouples the type design and replacement part dimensional attributes.
- 5.3.5 Measuring the dimensional variation of a type design part using the reverse-engineered datums created for a replacement part can make the type design part appear to have more variation compared to the replacement part. Further, if applicants use their replacement part datums to align the replacement and type design parts for a dimensional comparison, the variation in important features in type design parts can appear to be greater than it really is. For example, datums for replacement parts established by touching the external surfaces of type design parts will be different. In this case, the replacement parts will exhibit less variation than they would if they were compared using the datums that were developed for the type design part, but they will in fact have more variation.
- 5.3.6 Depending on the part, unintended expansion of the dimensional variation beyond the variation measured in type design parts can adversely affect the functional design of the replacement part and the integrity of interrelated hardware. For example, more variation in highly stressed turbine blade dovetails can increase the stress at the disk and blade contact surfaces, resulting in fracture of the blade dovetail or disk from accelerated wear or fatigue at the contact surfaces. More variation in adjoining rabbets at the interface between combustor hardware and casings can increase wear rates and shorten the maintenance interval. More variation in airfoil contours and load-bearing shafts can substantially affect their dynamic properties causing excessive flexure, stress, and failure from fatigue.
- 5.3.7 The applicant should clearly portray their selection of datums and reference dimensions in the data package and support their choices with evidence showing that their selections safeguard the part's functions and its interface with codependent critical parts, thereby preserving the engine's airworthiness.

5.4 Establishing Coordinate Systems.

- 5.4.1 Applicants can use various coordinate systems to define a part dimensionally. Examples of coordinate systems are Cartesian, Polar, Cylindrical, and Spherical. Choose the coordinate system appropriate for the part's shape, function, and features that require dimensional controls. Figure 3 shows examples of coordinate systems.

Figure 3. Examples of Coordinate Systems.

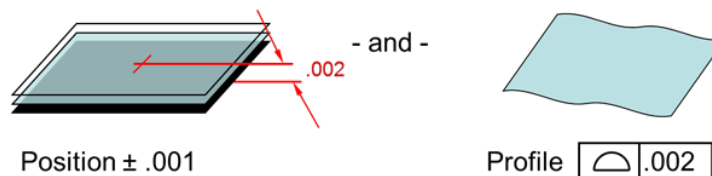
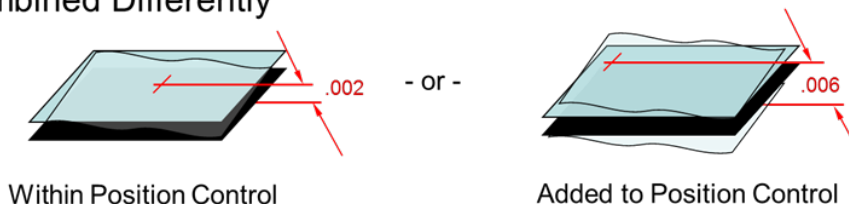


5.5 Non-Uniform Tolerances.

- 5.5.1 Measurements taken from type design parts should be sufficient in precision and density to detect the presence of non-uniform tolerances. Non-uniform tolerances in a part might indicate the presence of unique dimensional controls that support engine compliance throughout the type certificated operating range. They may also indicate where variation in local areas on a part has little or no effect on engine compliance.
- 5.5.2 Some reverse engineering processes assume the largest measured tolerance on a particular feature on a type design part applies evenly across the feature. This technique for replicating a tolerance is suitable if the maximum measured tolerance occurs over the entire feature or if a smaller measured tolerance is an artifact of how a part is seated in a fixture used for taking the measurements. However, non-uniform tolerances in a type design part may occur for various reasons. Reverse engineering methods should be capable of distinguishing non-uniform tolerances, and they should be explained in the safety assessment.
- 5.5.3 In some cases, TC holders build-in non-uniform tolerances into their type design parts, so they have inherent dynamic properties that accommodate certain engine system responses. In other cases, non-uniform tolerances can result from hand-blending procedures that TC holders allow in specific areas of the part, such as the trailing edge of some airfoil designs. Therefore, applicants should not automatically apply the largest measured variation in the type design part to the entire area or feature of the replacement part, because the resulting variation in the replacement part could exceed the range of variation intended by the TC holder for the type design part. Depending on the interrelationships with critical parts and complexities of the engine systems it affects, the effects of increased dimensional variation on engine compliance can be difficult to assess without engine experience or testing.

5.6 Combining Measured Variation.

- 5.6.1 The applicants' reverse engineering technique will determine how separate measurements taken from type design parts are combined on the replacement part drawing. There are numerous ways to combine measurements, and the various combinations can result in different amounts of dimensional variation in the part. For some design features, small variations in geometry can affect important functional properties, such as operating stresses, fatigue, vibration, wear, and failure modes. The way applicants combine separately measured tolerances can affect any of these functional properties. Therefore, to produce a credibly reverse-engineered part, applicants should ensure that their reverse engineering technique combines measured tolerances to account for the various stack-ups that can affect the part's function and interrelationships with other parts.
- 5.6.2 For example, a surface could have a tolerance for its position relative to a datum, and another tolerance for its profile. In this example, the surface profile tolerance is meant to be within the upper and lower bounds of the positional tolerance in the type design part. If the profile and positional tolerances are added together instead, the replacement part will have more variation than the type design part. This example shows there are circumstances where separate measurements from type design parts need to be combined in a specific way to reproduce the total variation in the replacement part.
- 5.6.3 Where assumptions are used in response to what is not known about the type design tolerances, it is appropriate to make conservative decisions that minimize the dimensional variation in a stack-up. It is also appropriate to implement validation methods to ensure the combined tolerances result in a replacement part that is functionally equivalent to the type design part. Contact stress between two parts is an example of a functional property that can be affected by small variations in dimensional characteristics. Combining measurements in a way that minimizes the total dimensional variation at the contact interface can help ensure the range of stress in the replacement part, and the part it contacts does not exceed the stresses intended for the type design part.
- 5.6.4 Figure 4 shows two measurements taken separately that are combined in different ways. An understanding of the functional design is necessary to determine which method duplicates the type design dimensional properties.

Figure 4. Combining Separate Measurements and Functional Design.**Separate Measurements****Combined Differently**

- 5.6.5 Physical differences from the type design part are determined by comparing the stack-up of dimensions that establish the total variation in the replacement part to the total variation measured in a sample population of type design parts. For example, separating part features such as nominal shape and contour and comparing them individually will not show if the replacement part geometry is within the type design part geometry. Applicants should stack the nominal shape and contour from the replacement part drawing and compare the resulting geometry to the corresponding measurements taken from the type design part. An overlay of the nominal shape, together with the contour around the nominal shape, will show the extent of physical differences between the part designs. Figure 5 shows an example of differences when considering total variation around nominal shapes.

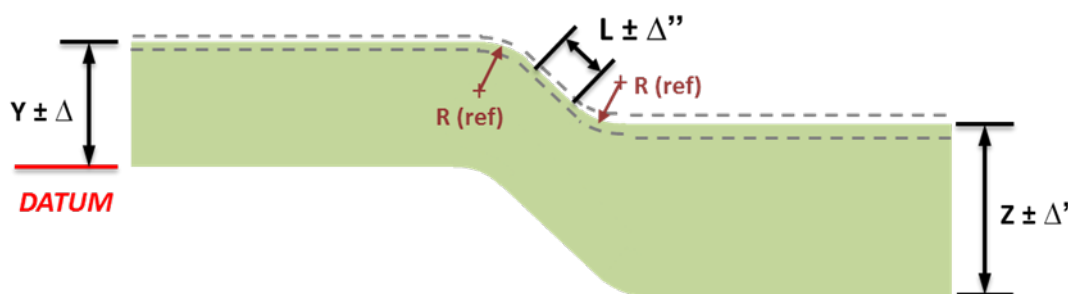
Figure 5. Example Showing Differences in Total Variation.

- 5.6.6 The method used to compare the geometry can also affect the results, showing the extent of dimensional differences in the replacement part. For example, using a “best fit” approach to quantify differences among features that are located by a datum on the part will not provide an accurate accounting of the physical differences and could result in unintended differences and, therefore, unsubstantiated functional differences in the replacement part.
- 5.6.7 Also, other dimensional controls within contours and tolerance bands could affect the stack-up of physical differences, like non-uniform tolerances and rates of dimensional changes on a surface. If present in the type design, these additional controls should be included in the assessments that determine the extremes of physical differences.

5.7 Transition Features.

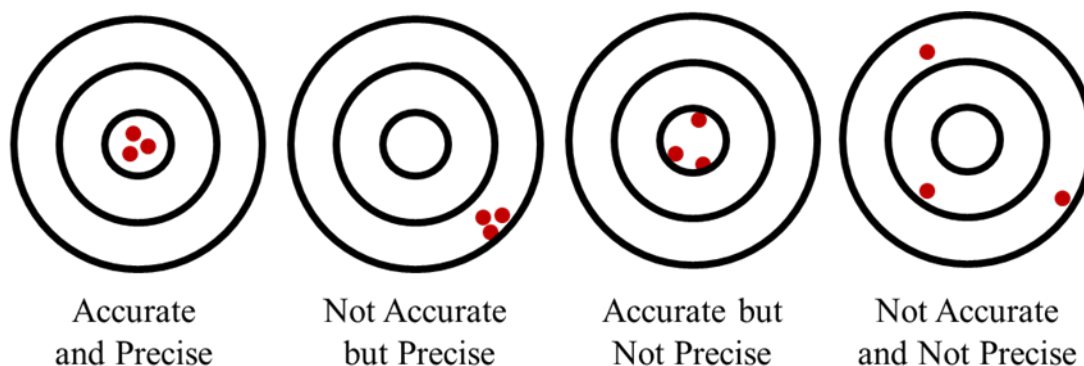
- 5.7.1 Corners, fillet radii, and transition radii are transition features. They can contribute substantially to the function of a type design part, interfacing parts, and higher-level assemblies. The dimensional variation in transition features might not be directly controlled. Instead, they might be an outcome of interrelated dimensions and tolerances. Conversely, the dimensional variation in some important features, such as load-bearing surfaces, is sometimes defined by the transition geometry. Figure 6 shows an example of how the dimension of a feature can depend on interrelated features. Differences in transition features have the potential for concentrating stresses, accelerating wear, and initiating fatigue cracks from typical mechanical and thermal loads. Therefore, to produce a valid design when using the comparative test and analysis method, the reverse engineering process should be capable of accurately identifying the dimensional characteristics for transition features, which could control or be controlled by adjacent features.

Figure 6. Dimension “L” is an Outcome of Other Dimensional Controls.



- 5.7.2 Compound fillets are also important features associated with static and rotating parts. They are used to reduce stress in specific areas and ensure parts, such as life-limited and life-assessed parts, meet their durability requirements. Therefore, to ensure that there are no changes inadvertently introduced in the proposed design, reverse engineering processes for replacement parts and repairs should be able to identify and replicate compound fillets that exist in type design parts.

- 5.7.3 To stay within the dimensional characteristics of the type design part, reverse-engineered transitions, or blends, care should be taken not to inadvertently introduce new features that do not exist in the type design part. For example, surfaces in contact with critical hardware are designed to preclude high-localized stress from raised features or sharp contact edges at interfaces. Therefore, to successfully apply comparative test and analysis methodology, applicants should evaluate the transition feature for detrimental geometry throughout the range of the reverse-engineered tolerance band.
- 5.8 **3D to 2D Translation.**
- 5.8.1 Some reverse engineering methods involve equipment and analytical techniques that develop a three-dimensional model from measurements taken from multiple type design parts. The three-dimensional model is subsequently converted to a two-dimensional drawing that defines the dimensional characteristics of the replacement part. The drawing dimensioning system incorporates datums, reference dimensions, tolerances, and geometric controls that are intended to represent the three-dimensional model. However, the choices applicants make to define the part on a drawing influence the amount of variation in individual features and the relative position of individual features.
- 5.8.2 The replacement part manufacturer develops its dimensioning system for their part. Since they do not have the TC holder's drawing, their drawing could implement different dimensional associations. These differences can potentially increase the variation in replacement parts beyond the limits specified on the TC holder's drawing. Dimensional differences can have undesired effects on the function of the part and interfacing parts. Therefore, applicants should not base their replacement part drawing definition solely on goals to facilitate manufacturing and inspection processes. Though there may be a need to develop drawings that correspond to in-process manufacturing requirements for the part, finished-part drawings are grounded in design criteria. Therefore, applicants should base their reverse-engineered dimensioning system on the part's various functional requirements. Applicants should also verify their dimensioning system is correct by assessments that consider it to be a potential source of variation.
- 5.9 **Precision and Accuracy.**
- 5.9.1 Precision is the number of digits used to define a value. Accuracy is the closeness of the measurement to the actual value. The precision of a measurement taken from a type design part should be adequate to capture the variation in the measured feature. The precision to which a feature is measured will affect the resulting variation in the reverse-engineered part. Figure 7 illustrates the difference between precision and accuracy.

Figure 7. Precision and Accuracy.

- 5.9.2 Compared to the rest of the part, certain features have minimal variation for various reasons. Maintaining the dimensional variation within a small range may be necessary to keep stresses below a design threshold, preserve the desired aeromechanical properties, control the location of the part within an assembly, or minimize wear between interfacing parts. Reproducing the dimensional variation ensures these properties and other functional properties are preserved in the replacement part.
- 5.9.3 The precision of a dimension on a drawing should not exceed the precision of the equipment used to acquire the measurement. Also, if a dimension on a drawing is a result of a stack-up of multiple dimensions that were acquired using various methods, then the precision of the resulting dimension should reflect the least precise measurement in the stack-up.
- 5.9.4 Normally, reverse-engineered measurement precision is determined by increasing the measurement precision until a threshold is reached where the measurements are consistent and no longer change with higher precision measurements. Measurement techniques that are less precise than the precision to which the type design part was manufactured will likely mask the actual variation, increase the variation in the replacement part, and may fail to reveal features that are in the type design.
- 5.9.5 Using industry standard manufacturing process yield alone to establish the precision of finished-part tolerances can reduce the dimensional accuracy of the replacement part if the type design part is qualified using inspection criteria that are tighter than the standard process yield. Similarly, reverse engineering techniques that offset nominal shapes or assign tolerances based on criteria from sources that are not associated with the type design part can affect the dimensional accuracy of the replacement part.
- 5.9.6 Selecting tolerances assuming there are common design practices among engine manufacturers and engine models is another way of introducing dimensional inaccuracies to replacement parts. Reverse engineering processes that use assumptions such as these can introduce substantial design differences to characteristics that affect the airworthiness of the part and result in a major design change to the engine.

5.10 Choice of Tolerance Control.

- 5.10.1 There are several options available for characterizing the dimensional variation of a part, which could affect the functional properties of the replacement part. For example, if the type design part defines the dimensional variation of a load-bearing surface by tolerances that control its contour and its distance relative to a datum, and the reverse-engineered surface is characterized only by a contour, then the position of the load-bearing surface relative to the datum can vary as much as the manufacturing process allows. This can cause loads to be concentrated or redistributed, among other features, resulting in stresses or wear that exceeds the maximum limits intended by the original part designers. Similarly, using a flatness requirement for a surface, instead of a profile, to control the variation in a load-bearing surface could change the load intensity, distribution, and wear properties at an assembly interface. Profile tolerance controls check all the measured points back to a datum (or datums), and flatness is the distance between two parallel, imaginary planes, which contains all of the points on the surface, independent of a datum. Figures 8 and 9 illustrate the flatness and profile tolerance controls.

Figure 8. Flatness Tolerance Control.

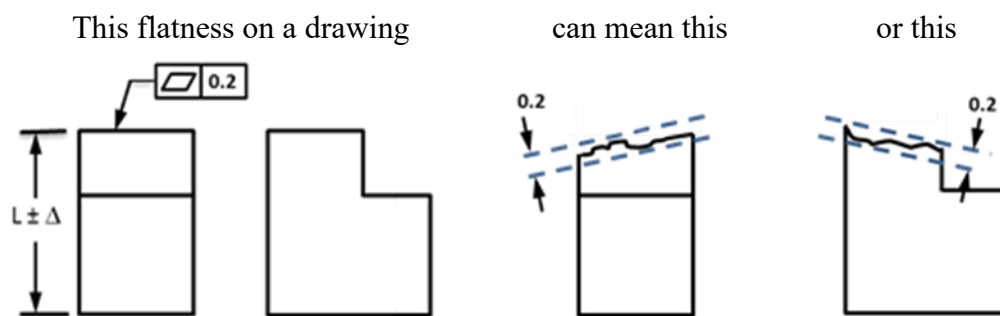
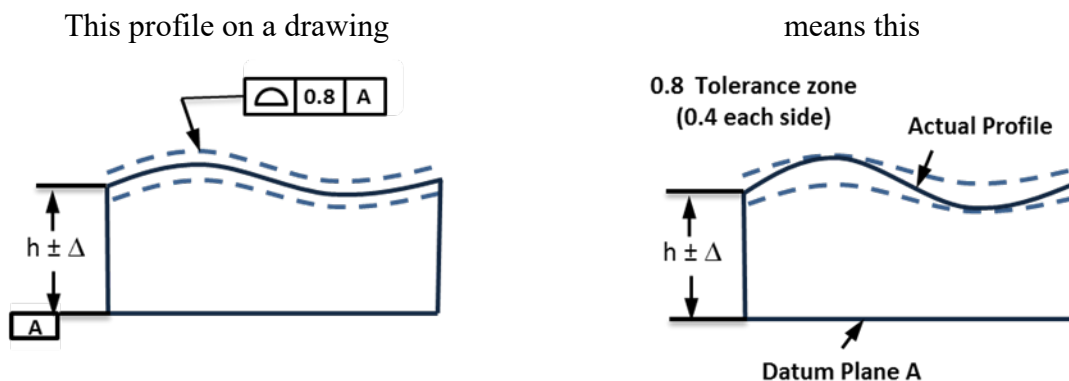
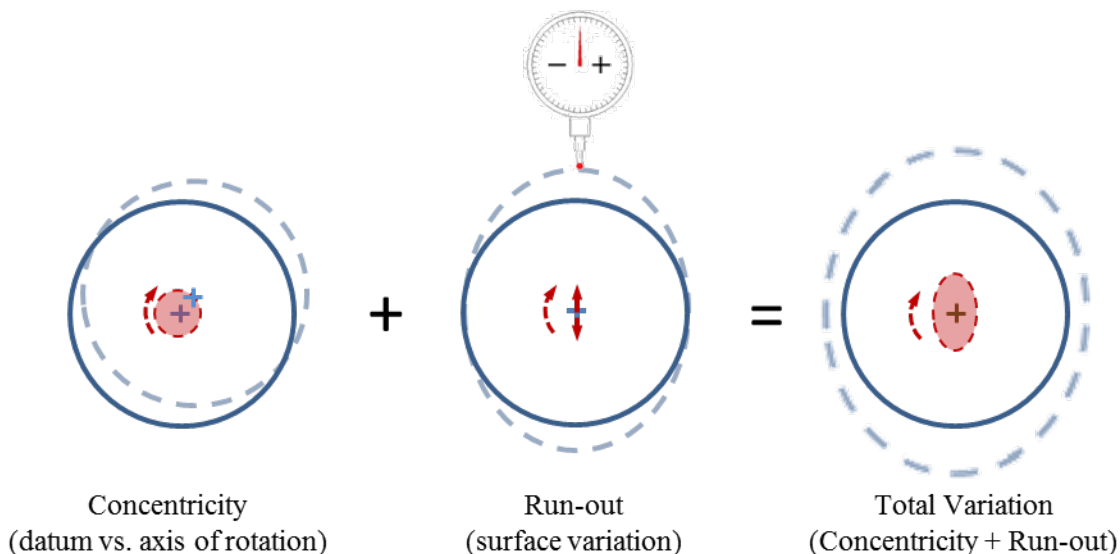


Figure 9. Profile Tolerance Control.



- 5.10.2 Differences in tolerance controls that affect surface-to-surface transition radii can result in unintended stress concentrations if the differences allow sharp features in contact surfaces and non-uniform surfaces that do not exist in the type design part. Sometimes, the magnitude of the effects from stress concentrations is only apparent when assessing the minimum and maximum material condition of the reverse-engineered part and interfacing parts. Therefore, applicants should carefully examine the part and its functions to determine the appropriate dimensional controls.
- 5.10.3 Concentricity, circularity, and run-out are also examples of tolerance controls that can affect the dimensional similarity and the functions of cylindrically shaped parts. When measuring the run-out of a cylindrical part, the tolerance zone is on the surface, whereas the tolerance zone for concentricity is at the center of the cylinder. Circularity is a form control that defines how much a surface of revolution may vary from a perfect circle. Figure 10 shows an example of the total variation in a cylindrical part. In this example, the total variation for the part is the summation of concentricity and run-out measurements.

Figure 10. Total Variation from Run-out and Concentricity.

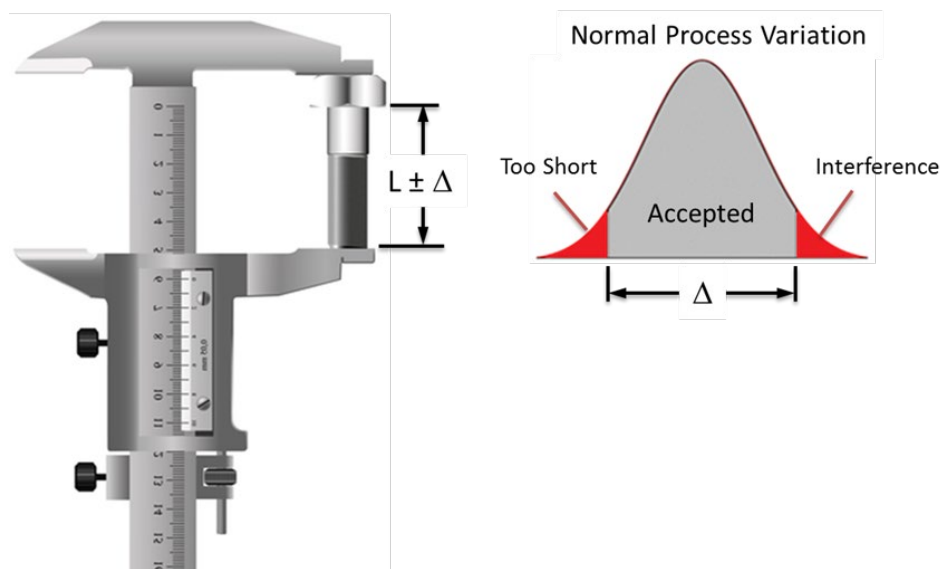


5.11 Statistical Dimensioning.

- 5.11.1 The drawing tolerances determined by reverse engineering for the proposed replacement part should not exceed the measured data taken from type design parts. The measurement data might exhibit a good fit with a particular statistical distribution, but this approach expands the range of dimensional variation beyond the measurements taken from the type design parts. To show a statistical distribution that accurately describes the full range of dimensional variation in a type design part, measurements from many more type design samples are necessary than the amount that is typically used for a replacement part project.

- 5.11.2 Inspection limits may restrict or bias dimensional properties of new parts to enhance performance, minimize wear, or improve reliability. Also, part-to-part bench tests usually do not include replacement parts that are made to the extent of their reverse-engineered dimensional limits, nor are the interfacing fixtures or type design hardware that are used in the tests. Depending on the criticality and sensitivities of higher-level assemblies and engine systems to dimensional variation in the part, the associated bench tests might not extract all the information necessary to verify there are no dimensional differences that could affect fit and function. Staying within the measurements taken from type design parts will ensure any special inspection criteria applied by the TC holder are captured in the replacement part design.
- 5.11.3 Inspection criteria may restrict or bias dimensional properties of new parts to enhance their performance, minimize wear, or improve overall system reliability. Dimensional inspection criteria are also used to screen parts produced by a statistically controlled manufacturing process to account for important design considerations such as tolerance stacks with critical mating parts, dynamic properties, and maximum moment weight. Figure 11 shows an example of how inspection limits can ensure the dimensional attributes of a part are compatible with the higher-level assembly.

Figure 11. Example of a Truncated Process Distribution.

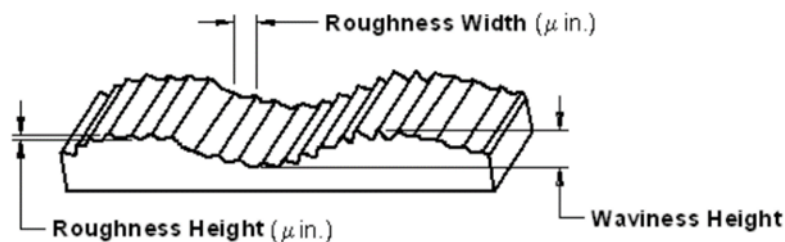


- 5.11.4 If statistical methods are used to smooth tolerances across a feature, exercise caution to ensure a sufficient number of type design samples are used to acquire the tolerances that will be smoothed. Also, to perform a valid statistical analysis, evaluate the adequacy of measurement density and precision of the area being smoothed to account for any possible non-uniform, restricted, or biased tolerances that might be present in the type design for proper function throughout the certificated engine operating range.

5.12 Surface Texture.

- 5.12.1 Surface texture may result from finishing processes or surface treatments that can affect the various functional properties of a part, such as fatigue, wear, performance, and reliability. For example, airfoil surface texture (also referred to as smoothness) affects airfoil fatigue properties and engine performance. The effect of differences in airfoil surface texture on fatigue in bench test conditions might be measurable with the proper comparative bench test, but the effect on engine performance is difficult to quantify without engine data or an analysis properly correlated to engine data. Therefore, the surface texture in a replacement part should be the same as the finish in the type design part, and the finishing processes that produce the type design surface texture should also be comparable.
- 5.12.2 Many techniques are available for measuring surface texture. The method used to quantify texture should be suitable for the part that is measured. New type design parts are the best source of information to characterize the texture and associated process for surfaces in contact. Figure 12 shows an example of various surface features that contribute to the texture. The measurement results will depend on how the surface is measured, the equipment that is used, and how the contributing parametric features are analyzed.

Figure 12. Various Parametric Features to Surface Texture.



- 5.12.3 Surface texture can result from a surface treatment that produces a compressive layer, such as peening or split-sleeve cold expansion of holes. A compressive surface layer improves fatigue resistance and the durability of a part and helps the engine achieve its certificated performance requirements. The presence of a compressive layer is not always evident from an inspection of the surface texture. Careful examination of the sub-surface material condition might be necessary to detect a compressive layer, which could involve destructive tests with finished type design parts. Processes that remove material for smoothing surfaces that have a compressive layer to improve component performance can defeat the durability benefits of the compressive layer.

- 5.12.4 Engine manufacturers develop their finishing methods, so there is no industry specification delineating the process and resulting surface condition or variation. Sometimes the finishing process is necessary to meet higher assembly design requirements, such as bolted joint integrity under various operating loads and flight conditions. These circumstances warrant comparative testing to verify the finishing process selected for the replacement part results in the same level of safety as the type design part.

5.13 Influence on Critical Parts.

- 5.13.1 A non-critical part can influence the integrity of a critical part in varying degrees. The industry generally refers to these parts as “influencing parts.” The influence can be from direct physical contact with the critical part or by the effect the part has on the conditions around the critical part. Dimensional differences in non-critical, influencing parts can have a significant effect on critical parts when they affect contact stresses or the conditions that maintain the operating environment within certain limits. The validation procedures for showing equivalence to non-critical, influencing type design parts should provide enough insight to verify that the engine data that was developed from a direct showing of compliance to 14 CFR 33.70 is not invalidated.
- 5.13.2 As described in this AC, the way an applicant dimensionally defines a part involves decisions for selecting datums and coordinate systems, how measurements are combined, and choosing measurement techniques. As shown in paragraphs 5.2 and 5.5 of this AC, some assumptions can cause the variation in replacement parts to exceed the variation in the type design part. Understanding the effect that these choices have on the part, and its influence on other parts is important. For example, preserving the stress at the interface between an influencing and critical part could require measurements from both parts at the interface. These measurements will provide important information about the total variation in the type design assembly at the interface and can help determine the dimensioning method that results in an equivalent amount of variation in the replacement part.
- 5.13.3 Dimensional differences in influencing parts tend to result in major changes in design because of the direct effects the differences have on critical parts. Assessing the magnitude of the effect dimensional differences have on engine systems and critical parts will likely require data from specific locations in the engine under certain operating conditions or from validated analytical techniques that are correlated to engine data.
- 5.13.4 Dimensional differences will likely exist in critical replacement parts and repairs that substantially remanufacture type design parts. Dimensional differences in critical parts can affect their ability to meet the prescribed integrity requirements of 14 CFR 33.27, 33.70, 33.76, 33.94, and TSO-C77b, paragraph 5.9, for example. If the critical part is life-limited, the applicant will need a method for assessing the life of the part with the differences, which involves data that is normally acquired by engine tests. Though not covered in this AC, differences in manufacturing, materials, engine configurations, and engine system environments also influence the integrity of critical parts.

- 5.13.5 Applicants usually demonstrate the extent of their knowledge about the interrelationships between non-critical parts and critical parts in their safety assessments. Also, some engine manuals provide a list of influencing parts.
- 5.14 **Minimum and Maximum Material.**
- 5.14.1 The replacement part design encompasses the geometry of the part manufactured to its dimensional limits. The minimum and maximum material condition of the part corresponds to the minimum and maximum dimensional tolerances. These material conditions include the cumulative effect of any dimensional differences, tolerances, and offsets from the nominal shape.
- 5.14.2 The results from replacement part assessments that show the part is functionally equivalent to the type design part pertain to the replacement part when it is manufactured to its reverse-engineered minimum and maximum material limits. Typically, measurements from a sample of type design parts are used to establish the dimensional limits for the replacement part. However, the methods that define the dimensional characteristics of the replacement part (datum selection, combining measured variation, choice of tolerance controls, etc.) will affect the reverse-engineered dimensional limits. Uncertainties in reverse engineering methods that can cause replacement parts to exceed the dimensional measurements taken from a sample of type design parts could expand the scope and expense of a project significantly.
- 5.14.3 A sample of parts produced for compliance testing does not usually include parts manufactured at the extremes of their drawing limits. However, these limits are important to consider for dimensional characteristics that interface with critical parts. When the integrity of a critical part or critical engine system is sensitive to variation in a part, the compliance showing should include assessments that extrapolate the results from the tested samples to account for the minimum and maximum material conditions. These data ensure there is a similarity in functional properties for the entire reverse-engineered design.
- 5.14.4 Applicants should examine the essential properties of a replacement part at its maximum material dimensions. For example, to properly apply the comparative test and analysis methodology, replacement turbine blades should not exceed the maximum moment weight measured from a sample of type design turbine blades. However, if the sample population of tested replacement blades pass this criterion, but the nominal reverse-engineered design is inadvertently biased toward the maximum material condition, then a maximum material replacement blade could exceed the maximum moment weight criterion. Supplemental data from an analysis correlated to the bench test data, in addition to the moment weight test data, can ensure the replacement part does not exceed the moment weight criterion when the part is manufactured to the maximum material condition.

- 5.14.5 The dimensional characteristics of a replacement part manufactured to the minimum material condition should also be evaluated. The minimum material condition can influence the stress in these parts in various ways. For example, the stress at load-bearing surfaces in replacement parts will be adversely affected if the minimum material condition causes the load-bearing area to drop below the minimum allowable area in the type design. Similarly, high stresses can result when the minimum material condition increases a stress concentration or results in unintended sharp features that do not exist in type design parts. Sharp features can result when a feature is defined without considering the transition geometry between surfaces in various combinations of minimum and maximum material conditions. If a sharp surface transition is in contact with another surface, it will likely result in improper seating between the parts that are in contact and high stresses that can cause localized fretting, premature wear, or fatigue failures.
- 5.14.6 Figures 13 and 14 illustrate how dimensional differences between a replacement part and a type design part can lead to functional differences and latent engine effects. The issues shown in these figures may not be detectable from a sample of replacement parts. Measurements from a sample of interfacing type design parts will help ensure the dimensional stack-up with the replacement part will result in proper fit and function when it is manufactured to its reverse-engineered dimensional limits. This consideration is especially important for parts that can influence the integrity of critical parts and engine systems.

Figure 13. Minimum Material Replacement Part Resulting in a Higher Contact Stress.

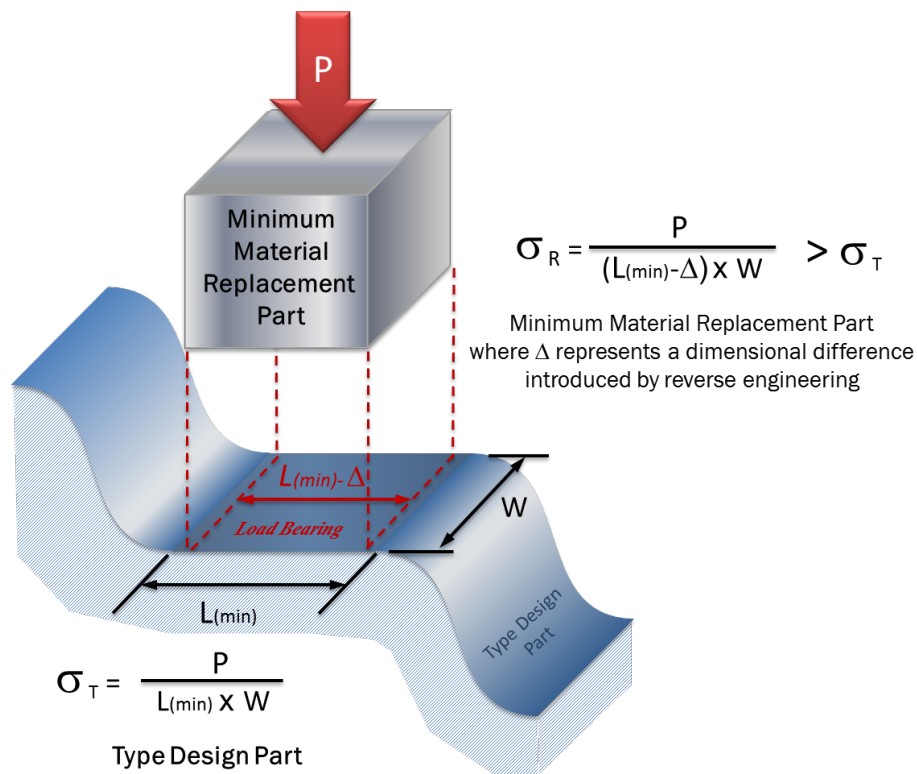
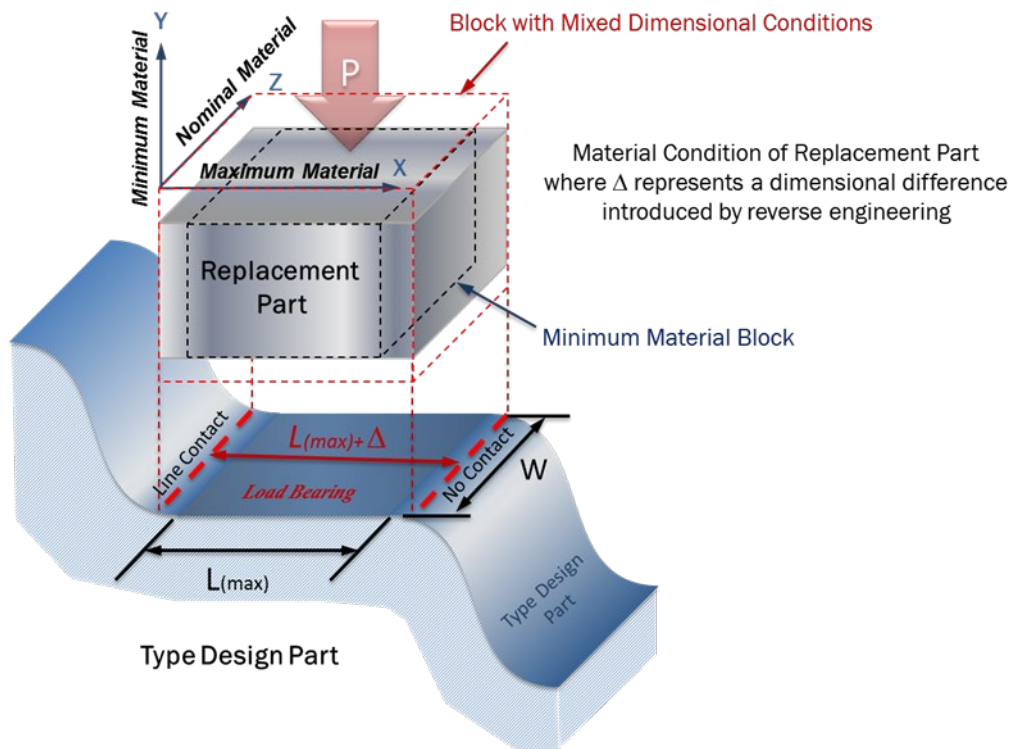


Figure 14. Maximum Material Replacement Part Resulting in a Higher Contact Stress.



5.15 Configuration Management.

- 5.15.1 TC holders develop configuration management programs based on the assumption that their customers will use their products and services throughout the engine lifetime. The TC holder has an internal design, quality, and manufacturing systems that flow into the configuration management programs they provide to their customers. Therefore, the TC holder publishes just the portion of their engine lifecycle management information that will be accomplished by their customers. This information ensures their engines are in a condition for safe operation when used with their maintenance instructions and other airworthiness programs. Providers of replacement parts have procedures for design, quality, and manufacturing systems that may or may not be compatible with the TC holder's configuration management program. Therefore, the following considerations could be important to applicants that intend to stay within the dimensional characteristics of a type design part.

- 5.15.2 An example of a TC holder quality system that safeguards their engine configurations is the Material Review Board. This system assesses non-conforming parts for compensating factors to determine if the part and the engine that uses the part can be managed with the existing ICA. Non-conforming TC holder parts are not within the intended type design, but they might be among the parts used for reverse engineering a PMA design. Nonconformities can include dimensional characteristics that are outside the TC holder's drawing limits. The TC holder does not publish the nonconformity or compensating factors that make the part eligible for installation because these details are captured and managed under their quality system. If the applicant measures a sufficient quantity of the TC holder's parts to perform a statistical analysis, they should test the population for outliers that may indicate parts that were accepted into service despite being outside the approved design tolerance.
- 5.15.3 Configuration control programs can involve grouping parts for assemblies, and selling them together, based on certain dimensional characteristics that maintain the integrity of higher-level assemblies. Sometimes, part suppliers will provide individual parts that are normally grouped with other parts by the TC holder. Failure to recognize higher-level assembly design criteria for certain propulsion systems has resulted in safety concerns. Examples of parts that could be managed this way are piston and sleeve combinations, interfacing gears, and parts that assemble with an interference fit.
- 5.15.4 The TC holder can also hand-select parts for certain engine models based on where the parts fall in the range of manufacturing variation, but should ensure that doing so does not invalidate the maintenance and configuration management programs they provide to their customers. Depending on their internal engine configuration management systems, the TC holder may not indicate that they segregate these parts at assembly. Typically, repairs to these parts are classified as major. Sometimes the dimensional characteristics of parts change after they are installed in higher-level assemblies. These changes can result from plastic deformation or machining after assembly. Physical changes such as this can preclude reverse engineering some parts that are extracted from higher-level assemblies.
- 5.15.5 TC holders often use the same part in different engines or multiple locations within engines, components, and accessories. This approach to managing engine configurations can help reduce the logistics costs for customers and lower the production costs for engine manufacturers. However, the upward compatibility of approved reverse-engineered parts to more demanding engine environments or across engine models where the same part number is used is not inevitable. For example, validation procedures for a replacement part eligible for installation in multiple engine models and assemblies should account for the full certificated performance of the most demanding engine and the various assemblies that could stress and fail the part in different ways. Assessments and tests that account for everywhere the part is used will help mitigate the risk of underestimating the criticality of the part, overlooking important reverse engineering criteria, and ensure any differences in the part are minor.
- 5.15.6 The compliance methods under test reports and computations provide alternatives to basic engineering analysis and side-by-side comparisons. General analysis, or direct compliance, allows applicants to address uncertainties about TC holder parts and how engine configurations are managed.

5.16 Coatings.

- 5.16.1 Some type design parts are coated, so the coating becomes part of the reverse-engineered design for a replacement part. In this case, applicants duplicate the coating as part of the overall effort to copy the type design part.
- 5.16.2 If an applicant is copying a type design part in parallel with its type design coating, the total stack-up with the coating is included in the assessment for dimensional similarity. The stack-up includes the part's nominal shape and tolerances, the coating thickness and tolerances, and the coating coverage tolerances. Paragraph 5.6 of this AC provides additional information about assessing replacement and type design parts for dimensional differences. Examples of dimensional properties that involve coatings are thickness, taper at the interface between two parts, transitions from coated to non-coated surfaces, and airfoil leading edge contours.
- 5.16.3 Parts that operate in the gas-path are highly customized designs that evolve with experience. Airfoil contours, moment weights, tolerances, contact areas, and aeromechanical properties can be affected by coatings. Differences in the dimensional characteristics of gas-path hardware present substantial challenges for replacement parts and repairs because the performance data acquired from engine certification tests and engine experience, such as erosion rates, are directly affected by the coating. For example, some highly-loaded blade dovetail coatings have special dimensional requirements to prevent failure from overstressed conditions at the interface with a life-limited part. Therefore, to meet § 21.303(a)(4), compliance data for replacement gas-path parts with coatings should provide enough insight to verify that the engine data that was developed from a direct showing of compliance is not invalidated.
- 5.16.4 New coatings are sometimes developed to replace the type design coating, or coatings are added to a repair to improve resistance to environmental effects, such as corrosion. Replacement part designs might also change the coating areas or recondition surfaces before applying the coating. It is not appropriate to rely on assumed engine effects from dimensional differences or assume the applicability of ICA for projects that add coatings or change the distribution of coatings. These projects are outside the scope of this AC because assessing the effect of the coating on various airworthiness requirements often involves direct compliance.

5.17 Test Part Conformity.

- 5.17.1 Applicants should accomplish conformity for all replacement parts that will be used in the comparative assessments. Conformity ensures the tested parts are representative of the proposed design.
- 5.17.2 In accordance with 14 CFR 21.310(b), parts that conform to the replacement part drawing are considered eligible for certification testing. Parts that do not fully conform to the replacement part drawing and are proposed for certification testing must be substantiated by showing that the non-conforming feature, or features, will not affect the property being assessed by the test.

- 5.17.3 If certification tests show performance differences between the type design part and the replacement part, the replacement part manufacturer should verify that the dimensional attributes of the tested parts meet their drawing requirements. If they find their part to be conforming, they should then determine if there are other reasons for the performance differences. For example, the performance differences might be from differences in manufacturing processes, material properties, or how samples were tested. If the test involves comparative destructive evaluations, such as fatigue testing, the conformity assessment should be accomplished before the test to qualify the test data for certification purposes and to confirm the effects of any corrective design or manufacturing remedies.
- 5.17.4 Applicants might find their parts conform and do not detect any anomalies in their manufacturing and quality systems that explain the performance differences. In this case, applicants should reexamine the reverse engineering process they used to develop the design of the replacement part for potential sources of variation in features that could have influenced the outcome of the test.
- 5.18 **Dimensional Development.**
- 5.18.1 Some engine parts have internal cavities and labyrinth passageways that allow cooling air to pass through the core of the part to remove heat from external surfaces that are exposed to hot gas temperatures. These internal features provide a thermal balance in the part that inhibits deterioration and thermally induced failure modes, such as cracks and creep. The manufacturing techniques used to create internal features can involve processes that result in residual stresses, such as casting.
- 5.18.2 When applicants use destructive methods to inspect and quantify the dimensional characteristics of internal features in parts that have residual stresses, the resulting geometry of the sectioned part could be different from what it was when the part was in one piece. There could be a tendency for the part to shift or spring back when residual stress is relieved as the part is progressively sectioned for the dimensional analysis. When this occurs, the resulting measurements acquired from the type design part will not provide accurate dimensional information for the replacement part definition.
- 5.18.3 Applicants that use destructive methods to reverse engineer a type design part should use suitable methods that ensure the parameters being acquired are not affected by geometric shifts that can occur from relieving residual stress. Figure 15 shows an example of surfaces that can shift during a destructive evaluation. Figure 16 shows some dimensional properties that are independent of the physical distortion that occurs when the residual stress is relieved.

Figure 15. Effects of Residual Stress from Destructive Evaluation.

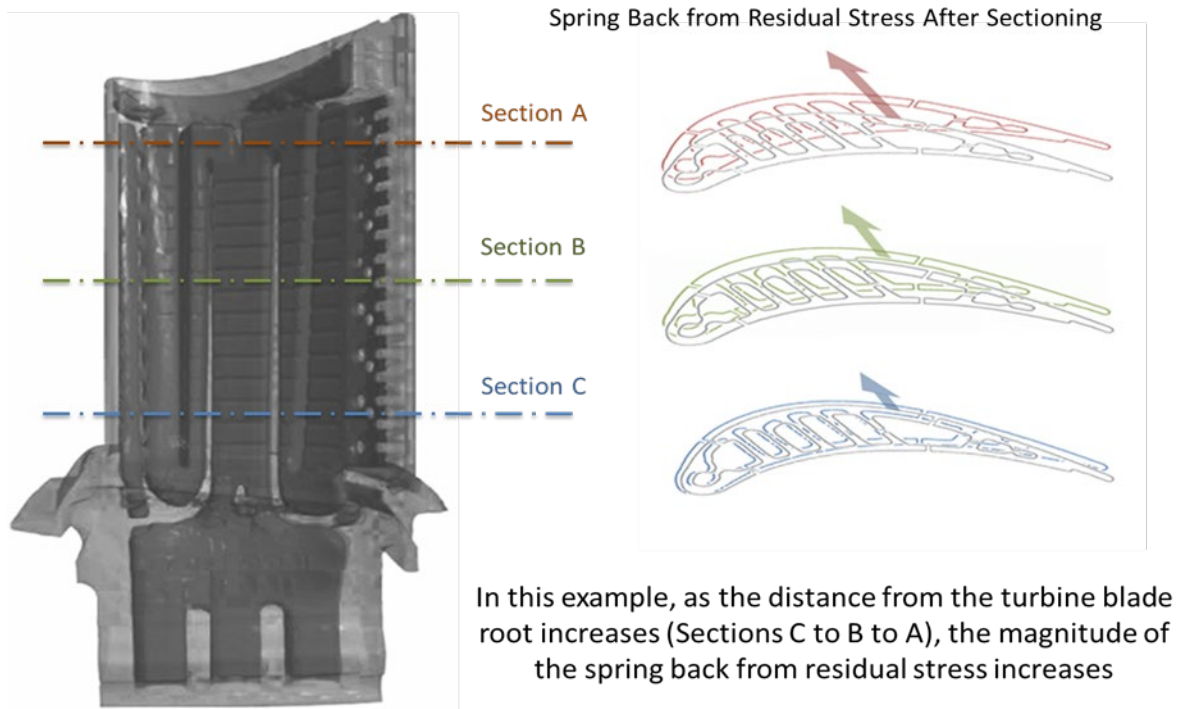
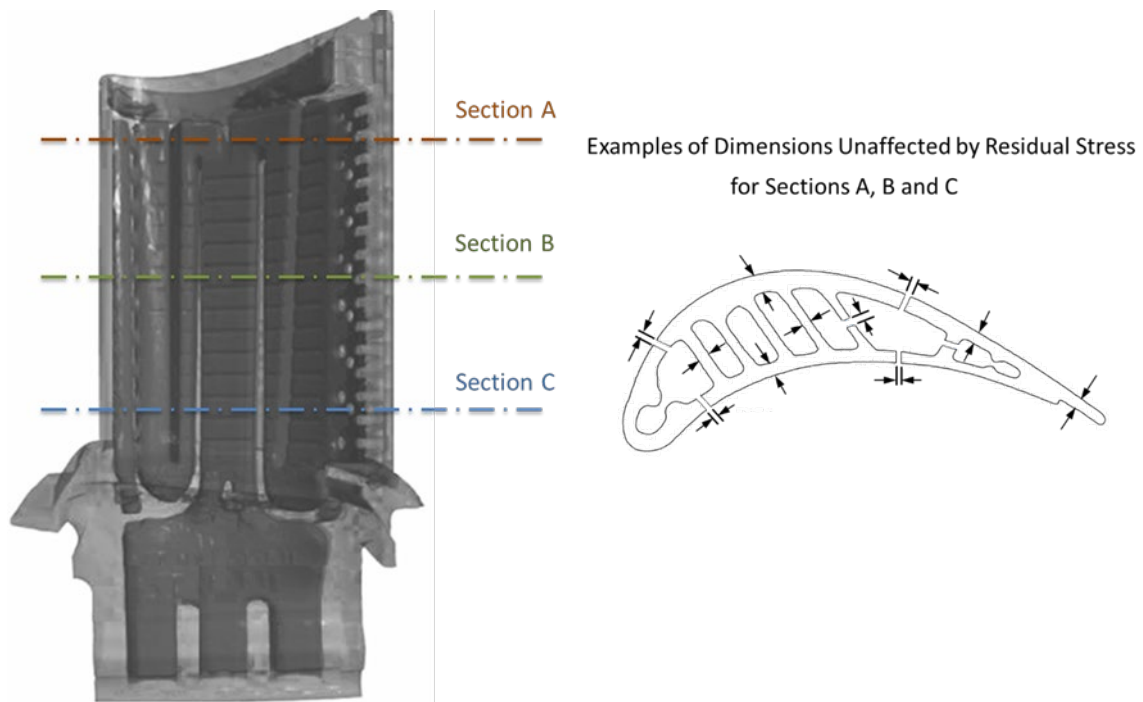


Figure 16. Features Independent of Residual Stress during Destructive Evaluation.



5.19 Dimensional Validation.

- 5.19.1 In accordance with 14 CFR 21.303(a)(4), test reports and computations for the replacement part must show that the engine continues to comply with its airworthiness requirements, up to the certificated performance requirements, when the replacement part is built anywhere within the limits of its approved design. Similarity in dimensional variation between the type design and replacement parts depends on the extent to which they are dimensioned similarly. Unless there is a licensing agreement, there is a potential for the replacement part drawing to have differences in dimensioning criteria or overlooking design attributes. These differences can increase the amount of variation in the replacement part.
- 5.19.2 The FAA procedures for approving replacement parts allow applicants to develop data from part-to-part comparative tests using the sample sizes prescribed in available advisory material. When sample sizes are prescribed by the guidance, they are based on the condition that the sample population meets certain prerequisites and that the test methods and test criteria used for the comparisons are consistent with the guidance. For example, a prerequisite for using a prescribed sample size could include a condition that the replacement part is designed to be within measurements taken from the type design part.
- 5.19.3 The sample of replacement parts used for compliance testing will not likely represent the full range of dimensional variation in the reverse-engineered design. Moreover, when applicants select test samples from a single manufacturing lot, the physical properties of the test samples could be untypically uniform. Therefore, functional test results could be misleading if the dimensional variations in the replacement parts represent a small range, or a bias, within the potential tolerance band, and engine compliance is sensitive to the effects of the dimensional variation in the part. The conformity data should show if the sample of replacement parts have any dimensional characteristics that could limit the applicability of the compliance test results to the specific samples being tested and not to production parts that exhibit typical process variation.
- 5.19.4 If applicants develop a compliance plan assuming the assessments would verify dimensional similarity, but the results demonstrate differences in the replacement part, they should revise the compliance plan. The revised compliance plan should include any necessary assessments to account for the effects of the differences on engine compliance. Alternatively, applicants could modify the replacement part design to align its functional performance with the type design part. This additional activity may require more specimens and tests than were proposed in the original certification plan, and tests involving higher-level assemblies using a range of engine operational boundary conditions or a new project application and methods of compliance. Though not covered in this AC, differences resulting from the replacement part manufacturing processes and materials should also be resolved similarly.

5.20 Maintenance Manuals.

- 5.20.1 TC holders develop maintenance manuals for their engines. The serviceability and return-to-service instructions for individual parts are based on the engine configuration, production processes, and quality systems that flow into their manuals. For example, the tests, inspections, and limits in the manuals account for aspects of the type design that might have changed since it was new and not for features that continue to conform to the type design drawing. Therefore, TC holder maintenance manuals normally do not instruct operators to check all the dimensional characteristics and qualities that affect the airworthiness of the part. They also do not typically implement tests and inspections to account for differences that an applicant might introduce to a replacement part by reverse engineering.
- 5.20.2 Applicants that base their replacement part designs solely on the information available in TC holder maintenance manuals may have introduced dimensional differences into new parts and repairs and subsequently introduced differences that could affect engine compliance. Therefore, the TC holder maintenance procedures do not provide sufficient information to substantiate reverse-engineered designs or new repairs. Thus, maintenance manuals do not apply to the replacement part until after the replacement part is found to be equivalent to the type design part through suitable comparative assessments or is shown to be compliant with applicable airworthiness standards using general analysis (direct compliance).
- 5.20.3 The test procedures in maintenance manuals prescribed by appendix A to Part 33 are meant to verify the characteristics of the part that are affected by the repair. The tests do not substantiate reverse-engineered parts or repairs that substantially remanufacture type design parts. For example, some airflow tests are intended to check for damage or blockage that might have occurred during the repair. Though the test results may show that at room temperature, ambient air will flow similarly between two air-cooled turbine part designs; it is not likely the tests specified in the manual will provide any useful insight into how the relative cooling in each design compares in an engine environment. Also, these tests will not reveal which features on the part have a substantial influence on the engine system.

6. SUGGESTIONS FOR IMPROVING THIS AC.

If you have suggestions for improving this AC, you may use the Advisory Circular Feedback Form at the end of this AC.

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ELGAS

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Subject: AC 33-12 Geometry and Dimensional Considerations for Comparative Test and Analysis for Turbine Engine and Auxiliary Power Unit (APU) Replacement, and Repaired Parts

Date: _____

Mark all appropriate line items:

An error (procedural or typographical) has been noted in paragraph _____ on page _____.

Recommend paragraph _____ on page _____ be changed as follows:

In a future change to this AC, please cover the following subject:
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