PRODUCT DESIGN, ADDITIVE MANUFACTURING QUALITY INSPECTION OF A SCANNED PART WITH IT'S CAD MODEL

a project report

submitted in partial fulfilment of

the requirements for the award the degree of

BACHELOR OF ENGINEERING AND TECHNOLOGY

IN

MECHANICAL ENGINEERING

BY

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DECLARATION

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Place: New Delhi

Date: 22 December, 2017

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On the basis of declaration submitted by **ISMAEL WASIM(Roll No: 14BME0033), YASH CHATURVEDI(Roll No: 14BME0042), UDIT AGARWAL(Roll No: 14BME0054)** student of B. Tech. in Mechanical Engineering, I hereby certify that the project report titled **"QUALITY INSPECTION OF A CAD MODEL VS A SCANNED MODEL"** which is submitted to the Department of Mechanical Engineering, Faculty of Engineering and Technology, Jamia Millia Islamia, New Delhi in partial fulfillment of the requirement for the award of the degree of Bachelor of Technology in Mechanical Engineering is an original work carried out by them under my guidance and supervision.

To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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ABSTRACT

3D inspection process is getting more and more interest for manufacturing industries as it helps to carefully check the expected quality of the released products. Much more attention is oriented to optical devices able to quickly capture the whole shape of the product providing many useful information on the process variability and the deliverability of the key characteristics linked to the quality of the product/process. Although the optical control of 3D scanners is mature enough, many factors may influence the quality of the scanned data. These factors may be strictly related to internal elements to the acquisition device, such as scanner resolution and accuracy, and external to it, such as proper selection of scanning parameters, ambient lighting and characteristics of the object surface being scanned (e.g. surface color, glossiness, roughness, shape), as well as the sensor-to-surface relative position. For the 3D laser-based scanners, the most common on the market, it would be of great industrial interest to study some scanning factors mainly affecting the quality of the 3D surface acquisitions and provide users with guidelines in order to correctly set them so to increase the massive usage of these systems in the product inspection activities.

The quality of the product that is produced by the Additive manufacturing technologies has continuously being improved over the last years. The product can be formed either through a CAD model or through scanning of the object. But of the two processes of preparing a SLA file the net output product will have different quality (in term of dimensions) with reference to the actual object. In this report, we have outline the comparison of the two models using a cloud based software named as Geomagic Control X. and finally a comparison of the two has been made as the conclusion. And depending on the availability and requirement of the industry one of the two can be chosen.

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PART I

OBJECTIVE

The primary of our projective is to learn various techniques of **Product Designing** and further using **3D Scanning** to perform **Quality Inspection** on a custom nut and screw made in Solidworks and Inspection done in 3D Systems’ GeoMagic Control X.

Need for study

The need of study of the various concept development and design tools is that it helps in developing a relationship between the problem definition, identified as customer needs, and the design of the products physical parameters complying with the specifications required. The concepts or tools used to achieve a final product are

- TRIZ tools-
  The Theory of Inventive Problem Solving, known by the acronym “TRIZ,” is a problem-solving methodology tailored to provide innovative solutions for scientific and engineering problems.

- Reverse Engineering-
  Reverse engineering, also called back engineering, is the processes of extracting knowledge or design information from anything man-made and re-producing it or re-producing anything based on the extracted information. The process often involves disassembling something and analyzing its components and workings in detail.

- Surface and Solid Modelling-
  A mathematical technique for representing solid-
  appearing objects. Surface modeling is amore complex method for representing objects th an wireframe modeling, but not as sophisticated as solid modeling. Surfacemodeling is wi dely used in CAD (computer-aided design) for illustrations and architectural renderings. It is also used in 3Danimation for games and other presentations.

- Rapid Prototyping-
  The Rapid Prototyping techniques is very useful in developing prototype models for testing and refinement purposes. These include use of additive manufacturing techniques (3D Printing) to prototype a 3D CAD model. Full scale models can be directly printed thus reducing the concept development cycle time and also reducing the cost incurred when using expensive tooling.

Thus, an in-depth study of these tools is required to achieve the final product specifications conforming to the customer needs.

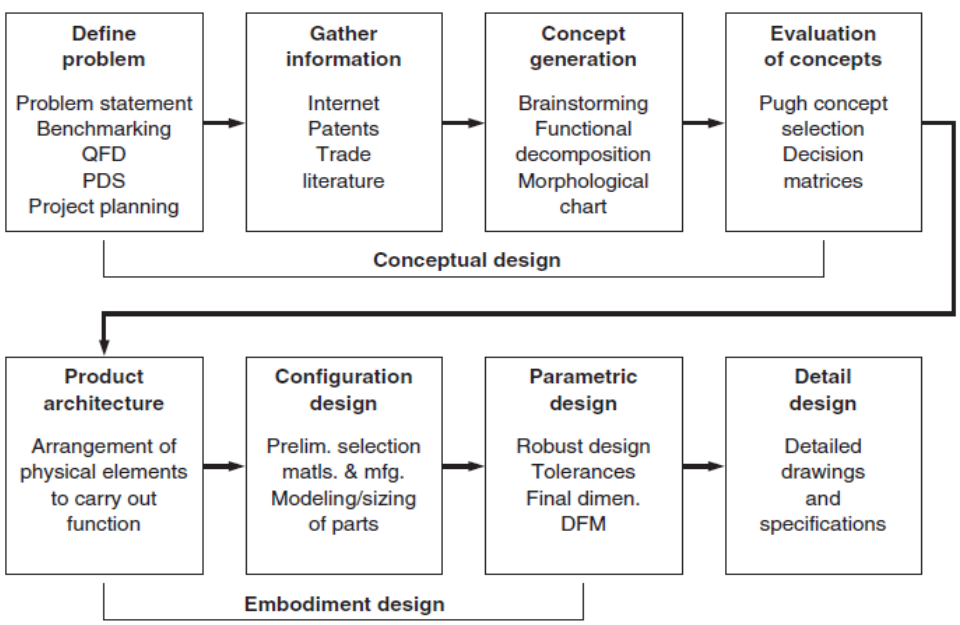
Design Process

What is design?

Webster's dictionary says that to design is "to fashion after a plan," but that leaves out the essential fact that to design is to create something that has never been. An engineering designer practices design by that definition, but so does an artist, a sculptor, a composer, a playwright, or many another creative member of our society.

> "Design establishes and defines solutions to and pertinent structures for problems not solved before, or new solutions to problems which have previously been solved in a different way."

The ability to design is both a science and an art. The science can be learned through techniques and methods, but the art is best learned by doing design. It is for this reason that the design experience must involve some realistic project experience. The product design process has experienced huge leaps in evolution over the last few years with the rise and adoption of 3D printing. New consumer-friendly 3D printers can produce dimensional objects and print upwards with a plastic like substance opposed to traditional printers that spread ink across a page.



Problem definition

Product development begins by determining what the needs are that a product must meet. Understanding any problem thoroughly is crucial to reaching an outstanding solution. This axiom holds for all kinds of problem solving, whether it be math problems, production problems, or design problems. In product design the ultimate test of a solution is meeting management's goal in the marketplace, so it is vital to work hard to understand and provide what it is that the customer wants. Fortunately, the product development process introduced in is a structured methodology that focuses specifically on creating products that will succeed in the marketplace.

It emphasizes the customer satisfaction aspect of problem definition, an approach not always taken in engineering design. This view turns the design problem definition process into the identification of what outcome the customer or end user of the product wants to achieve. Therefore, in product development, the problem definition process is mainly the need identification step.

Identify customer needs

Increasing worldwide competitiveness creates a need for greater focus on the customer's wishes. Engineers and business people are seeking answers to such questions as:

Who are my customers?

What does the customer want?

How can the product satisfy the customer while generating a profit?

1. Preliminary Research on Customer Needs

In a large company, the research on customer needs for a particular product or for the development of a new product is done using a number of formal methods and by different business units. The initial work may be done by a marketing department specialist or a team made up of marketing and design professionals.

The natural focus of marketing specialists is the buyer of the product and similar products. Designers focus on needs that are unmet in the marketplace, products that are similar to the proposed product, historical ways of meeting the need and technological approaches to engineering similar products of the type under consideration.

Clearly, information gathering is critical for this stage of design. Design teams will also need to gather information directly from potential customers. One way to begin to understand needs of the targeted customers is for the development team to use their own experience and research to date. The team can begin to identify the needs that current products in their area of interest do not meet and those that an ideal new product should meet. In fact, there's no better group of people to start articulating unmet needs than members of a product development team who also happen to be end users of what they are designing.

Brainstorming is a natural idea generation tool that can be used at this point in the process. It is such a familiar process that a brief example of how brainstorming can be carried out to provide insight into customer needs is given here.

2. Constructing a Survey Instrument

Regardless of the method used to gain information from customers, considerable thought needs to go into developing the survey instrument. Creating an effective survey requires the following steps. Determine the survey purpose. Write a short paragraph stating the purpose of the survey and what will be done with the results. Be clear about who will use the results.

Determine the type of data-collection method to be used. Surveys and closely scripted interviews are effective for compiling quantitative statistics. Focus groups or free-form interviews are useful for collecting qualitative information from current and targeted customers.

3. Evaluating Customer Surveys

To evaluate the customer responses, we could calculate the average score for each question, using a 1–5 scale. Those questions scoring highest would represent aspects of the product ranked highest in the minds of the customers. Alternatively, we can take the number of times a feature or attribute of a design is mentioned in the survey and divide by the total number of customers surveyed. We might use the number of responses to each question rating a feature as either a 4 or a 5.

4. Establishing the engineering characteristics

Establishing the engineering characteristics is a critical step toward writing the product design specification. The process of identifying the needs that a product must fill is a complicated undertaking. Earlier sections of this chapter focused on gathering and understanding the total picture of what the customer wants from a product. A major challenge of this step is to hear and record the fullness of customer ideas without applying assumptions. For example, if a customer is talking about carryon luggage they may say, “I want it to be easy to carry.” An engineer might interpret that phrase to mean, “Make it lightweight,” and set weight as a design parameter that should be minimized. However, the customer may really want a carry-on case that is easy to fit into the overhead luggage compartment of a plane. The carrying task is already easy due to the design innovation of wheeled luggage. Just knowing what a customer or end user wants from a product is not sufficient for generating designs. Recall that the design process only proceeds into concept generation once the product is so well-described that it meets with the approval of groups of technical and business discipline specialists and managers. The description fashioned for the approval to start design generation must be a set of all known design parameters, constraints, and variables. This set is comprised of solution-neutral specifications, meaning that the specification *at this time* should not be so complete as to suggest a single concept or class of concepts.

This description is a set of engineering characteristics that are defined as follows:

- ***Design Parameters.*** Parameters are a set of physical properties whose values determine the form and behavior of a design. Parameters include the features of a design that can be set by designers *and* the values used to describe the performance of a design. Note: It must be clear that designers make choices in an attempt to *achieve* a particular product performance level, but they cannot *guarantee* they will succeed until embodiment design activities are finalized.

- ***Design Variable***. A design variable is a parameter over which the design team has a choice. For example, the gear ratio for the RPM reduction from the rotating spindle of an electric motor can be a variable.

- ***Constraints***. Constraints are limits on design freedom. They can take the form of a selection from a particular color scheme, or the use of a standard fastener, or a specific size limit determined by factors beyond the control of both the design team and the customers. Constraints may be limits on the maximum or minimum value of a design variable or a performance parameter. Constraints can take the form of a range of values.

Customers cannot describe the product they want in engineering characteristics because they lack the knowledge base and expertise. Engineering and design professionals are able to describe products in solution-neutral form because they can imagine the physical parts and components that create specific behaviors. Engineers can use two common product development activities to expand and refresh their understanding of products of similar type to what they must design—**benchmarking** and **reverse engineering.**

Benchmarking

Benchmarking is a process for measuring a company's operations against the best practices of companies both inside and outside of their industry. It takes its name from the surveyor's benchmark or reference point from which elevations are measured. Benchmarking can be applied to all aspects of a business. It is a way to learn from other businesses through an exchange of information.

Benchmarking operates most effectively on a quid pro quo basis—as an exchange of information between companies that are not direct competitors but can learn from each other's business operations. Other sources for discovering best practices include business partners (e.g., a major supplier to your company), businesses in the same supply chain (e.g., automobile manufacturing suppliers), companies in collaborative and cooperative groups, or industry consultants. Sometimes trade or professional associations can facilitate benchmarking exchanges. More often, it requires good contacts and offering information from your own company that may seem useful to the companies you benchmark.

To overcome barriers to benchmarking, project leaders must clearly communicate to all concerned the project's purpose, scope, procedure, and expected benefits. All benchmarking exercises begin with the same two steps, regardless of the focus of the benchmarking effort. Select the product, process, or functional area of the company that is to be benchmarked. That will influence the selection of key performance *metrics* that will be measured and used for comparison. From a business viewpoint, metrics might be fraction of sales to repeat customers, percent of returned product, or return on investment.

Identify the *best-in-class companies* for each process to be benchmarked. A best in-class company is one that performs the process at the lowest cost with the highest degree of customer satisfaction, or has the largest market share.

Reverse Engineering or Product Dissection

A process similar to but narrower than benchmarking is *reverse engineering.* Reverse engineering is another name for product dissection. In its most unsavory embodiment, reverse engineering is done for the sole purpose of copying a product.

Reverse engineering gives a snapshot of how other designers have combined parts to meet customer needs. Product dissection entails the dismantling of a product to determine the selection and arrangement of component parts and gain insight about how the product is made. The "teardown" of a product is often a part of product benchmarking, but without the intent of copying the design. However, the collection of this type of benchmark information provides a better understanding of the solutions selected by the competition. Learning about a product, its components, and how it is made is easier when given access to engineering specifications, complete product drawings, manufacturing process plans, and the product's business plans. A design engineer is well acquainted with this documentation for the products produced by his or her own design team.

However, competitive performance benchmarking requires that the same information be obtained for competitors' products. In this case, the design engineer only has access to the product itself (assuming it is available on the open market). Product dissection is performed to learn about a product from the physical artifact itself.

The product dissection process includes four activities. Listed with each activity are important questions to be answered during that step in the dissection process.

1. Discover the operational requirements of the product. How does the product operate? What conditions are necessary for proper functioning of the product?

2. Examine how the product performs its functions. What mechanical, electrical, control systems or other devices are used in the product to generate the desired functions? What are the power and force flows through the product? What are the spatial constraints for subassemblies and components? Is clearance required for proper functioning? If a clearance is present, why is it present?

3. Determine the relationships between component parts of the product. What is the product's architecture? What are the major subassemblies? What are the key component interfaces?

4. Determine the manufacturing and assembly processes used to produce the product. Of what material and by what process is each component made? What are the joining methods used on the key components? What kinds of fasteners are used and where are they located on the product?

Discovering the operational requirements of the product is the only step that proceeds with the product fully assembled. Disassembling the product is necessary to complete the other activities. If an assembly drawing is not available with the product, it is a good idea to sketch one as the product is disassembled for the first time. In addition to creating an assembly drawing, thorough documentation during this phase is critical. This may include a detailed list of disassembly steps and a catalog listing for each component.

Engineers do reverse engineering to discover information that *they cannot access any other way*. The best information about a product is the complete product development file. This would include the product design specification and all other detail design documents. Reverse engineering can show a design team what the competition has done, but it will not explain why the choices were made. Designers doing reverse engineering should be careful not to assume that they are seeing the best design of their competition. Factors other than creating the best performance influence all design processes and are not captured in the physical description of the product.

Gather information

The need for information can be crucial at many steps in a design project. You will need to find these bits of information quickly, and validate them as to their reliability. For example, you might need to find suppliers and costs of fractional-horsepower motors with a certain torque and speed. At a lower level of detail, you would need to know the geometry of the mounting brackets for the motor selected for the design.

At a totally different level, the design team might need to know whether the new trade name they created for a new product infringes on any existing trade names, and further, whether it will cause any cultural problems when pronounced in Spanish, Japanese, and Mandarin Chinese. Clearly, the information needed for an engineering design is more diverse and less readily available than that needed for conducting a research project, for which the published technical literature is the main source of information.

The need for information permeates the entire engineering design or process design process. By placing the Gathering Information step between the Problem Definition and Concept Generation steps, we are emphasizing the critical need for information to achieve a creative concept solution.

Moreover, we think that the suggestions described in this chapter for finding information, and suggestions for sources of information, will be equally useful in the embodiment and detail design phases. You will find that as you progress into these phases of design the information required becomes increasingly technical. Of course, there is information, mostly marketing information that was needed to accomplish the problem definition.

Concept Generation

The most innovative products are the result of not only remembering useful design concepts but also recognizing promising concepts that arise in other disciplines. The best engineers will use creative thinking methods and design processes that assist in the synthesis of new concepts not previously imagined. Practical methods for enhancing creativity like brainstorming and Synaptic, developed in the 20th century, are now adapted and adopted as methods for generating design concepts. Creative thinking is highly valued across many fields of endeavor, especially those that deal with problem solving. Naturally then, creativity-enhancing methods are offered in workplace seminars, and recruiters of new talent are including creativity as a high-value characteristic in job applicants. This chapter opens with a short section on how the human brain is able to perform creatively, and how successful problem solving is seen as a demonstration of creative skill. Methods for thinking in ways that increase creative results in problem-solving contexts have been codified by specialists in several fields and are presented here.

Introduction to Creative Thinking

During past periods of growth in the United States, manufacturing managers believed that a product development organization could be successful with only a small number of creative people and the majority of the professionals being detail-oriented doers. Today's fierce worldwide competition for markets, new products, and engineering dominance is changing that mindset. Current business strategists believe that only organizations that create the most innovative and advanced products and processes will survive, let alone thrive. Thus, each engineer has a strong incentive to improve his or her own creative abilities and put them to work in engineering tasks. Society's view of creativity has changed over time. During the 19th century, creativity was seen as a romantic and mysterious characteristic. Scholars believed creativity to be an unexplainable personal talent present at the birth of an artist. It was thought that creativity was unable to be taught, copied, or mimicked. Individual creativity was a kind of genius that was nurtured and developed in those with the natural gift. The rising popularity of the scientific approach in the 20th century changed the perception of creativity. Creativity was measurable and, therefore, controllable. That perspective grew into the progressive notion that creativity is a teachable skill for individuals and groups. Today's managers recognize that the same kind of psychological and physiologically based cognitive processes that produce artistic creativity are used in the deliberate reasoning about and development of solutions.

Models of the Brain and Creativity

The science of thinking and the narrower science of design are classified as sciences of the artificial.

1. Exploring natural sciences is based on investigating phenomena that can be observed by the scientist. Unfortunately, it is not possible to observe and examine the steps that a creative person's brain follows while solving a problem or imagining a potential design. One can only study the results of the process (e.g., a problem solution or a design) and any commentary on how they developed as stated or recorded by the producer.

2. Advances in medicine and technology have expanded the boundaries of the activities of the brain that are observable and can be studied in real time. Modern neuroscience uses sophisticated tools such as functional MRI and positron emission tomography to observe the brain in action. The field is making great strides in revealing how the brain works by identifying which parts of the brain are responsible for particular actions. While technology is helping scientists to investigate the physical workings of the brain, cognitive scientists are still at work on investigating the workings of the human mind so that the best thinking skills and methods of thought can be learned and taught for the benefit of all.

Thinking Processes that Lead to Creative Ideas

Creativity is a characteristic of a person that is assigned based on what the person does. Researchers have discovered that, generally speaking, the thought processes or mental operations used to develop a creative idea are the same processes that are routinely used. Then the creativity question becomes, "How can some people use their brains to be more creative than others?" A group of researchers in the sciences named the successful use of thought processes and existing knowledge to produce creative ideas creative cognition. The good news about this view of creativity is that these strategies for achieving creative thinking can be accomplished by deliberate use of particular techniques, methods, or in the case of computational tools, software programs. The study of creativity usually focuses on both the creator and the created object. The first step is to study people who are considered to be creative and to study the development of inventions that display creativity. The assumption is that studying the thinking processes of the creative people will lead to a set of steps or procedures that can improve the creativity of the output of anyone's thinking. Similarly, studying the development of a creative artifact should reveal a key decision or defining moment that accounts for the outcome. This is a promising path if the processes used in each case have been adequately documented. The first research strategy will lead us to creativity process techniques like those introduced in Sec. 6.2.1 and 6.3. The second strategy of studying creative objects to discover the winning characteristic has led to the development of techniques that use a previous set of successful designs to find inspiration for new ones. Analogy-based methods fall into this category, as do methods that generalize principles for future use, like TRIZ.

Creativity and Problem Solving

Creative thinkers are distinguished by their ability to synthesize new combinations of ideas and concepts into meaningful and useful forms. A creative engineer is one who produces a lot of ideas. These can be completely original ideas inspired by a discovery. More often, creative ideas result from putting existing ideas together in novel ways. A creative person is adept at breaking an idea down to take a fresh look at its parts, or in making connections between the current problem and seemingly unrelated observations or facts. We would all like to be called "creative," yet most of us, in our ignorance of the subject, feel that creativity is reserved for only the gifted few. There is the popular myth that creative ideas arrive with flash-like spontaneity—the flash of lightning and clap of thunder routine. In keeping with the view of association, students of the creative process assure us that most ideas occur by a slow, deliberate process that can be cultivated and enhanced with study and practice. A characteristic of the creative process is that initially the idea is only imperfectly understood. Usually the creative person senses the total structure of the idea but initially perceives only a limited number of its details. There ensues a slow process of clarification and exploration as the entire idea takes shape. The creative process can be viewed as moving from an amorphous idea to a well-structured idea, from the chaotic to the organized, from the implicit to the explicit. Engineers, by nature and training, usually value order and explicit detail and abhor chaos and vague generality. Thus, we need to train ourselves to be sensitive and sympathetic to these aspects of the creative process. We need also to recognize that the flow of creative ideas cannot be turned on upon command. Therefore, we need to recognize the conditions and situations that are most conducive to creative thought. We must also recognize that creative ideas are elusive, and we need to be alert to capture and record our creative thoughts.

CREATIVE THINKING METHODS

Improving creativity is a popular endeavor. A search of Google under Creative Methods yielded over 12 million hits, many of them books or courses on creativity improvement. Over 150 creativity improvement methods have been catalogued. These methods are aimed at improving the following characteristics of the problem solver:

Sensitivity: The ability to recognize that a problem exists

Fluency: The ability to produce a large number of alternative solutions to a problem

Flexibility: The ability to develop a wide range of approaches to a problem

Originality: The ability to produce original solutions to a problem Following are descriptions of some of the most commonly used creativity methods. Many of these creativity improvement methods directly eliminate the most common mental blocks to creativity.

Brainstorming

Brainstorming is the most common method used by design teams for generating ideas. This method was developed by Alex Osborn to stimulate creative magazine advertisements, but it has been widely adopted in other areas such as design. The word brainstorming has come into general usage in the language to denote any kind of idea generation. Brainstorming is a carefully orchestrated process. It makes use of the broad experience and knowledge of groups of individuals. The brainstorming process is structured to overcome many of the mental blocks that curb individual creativity in team members who are left to generate ideas on their own. Active participation of different individuals in the idea generation process overcomes most perceptual, intellectual, and cultural mental blocks. It is likely that one person's mental block will be different from another's, so that by acting together, the team's combined idea generation process flows well. A well-done brainstorming session is an enthusiastic session of rapid, free-flowing ideas. Please review this section before proceeding further. To achieve a good brainstorming session, it is important to carefully define the problem at the start. Time spent here can help us to avoid wasting time generating solutions to the wrong problem. It is also necessary to allow a short period for individuals to think through the problem quietly and on their own before starting the group process. Participants in brainstorming sessions react to ideas they hear from others by recalling their own thoughts about the same concepts. This action of redirecting a stream of thought uncovers new possibilities in the affected team member. Some

New ideas may come to mind by adding detail to a recently voiced idea or taking it in different, but related, directions. This building upon others' ideas is known as piggy-backing or scaffolding, and it is an indicator of a well-functioning brainstorming session. It has been found that the first 10 or so ideas will not be the most fresh and creative, so it is critical to get at least 30 to 40 ideas from your session. An important attribute of this method is that brainstorming creates a large number of ideas, some of which will be creative. The evaluation of your ideas should be done at a meeting on a day soon after the brainstorming session. This removes any fear that criticism or evaluation is coming soon and keeps the brainstorming meeting looser. Also, making the evaluation on the day after the idea generation session allows incubation time for more ideas to generate and time for reflection on what was proposed. The evaluation meeting should begin by adding to the original list any new ideas realized by the team members after the incubation period. Then the team evaluates each of the ideas. Hopefully, some of the wild ideas can be converted to realistic solutions. Brainstorming is used for generating ideas for design concepts in conceptual design. It is also used in the problem definition step of design. In doing this the best approach is to think of all the possible limitations or shortcomings of the product, in what might be termed reverse brainstorming. One way to help the brainstorming process is to break up the normal thought pattern by using a checklist to help develop new ideas. The originator of brainstorming proposed such a list, which Eberle modified into the acrostic SCAMPER. Generally, the SCAMPER checklist is used as a stimulant when the flow of ideas begins to fall off during the brainstorming activity.

Refinement and Evaluation of Ideas

The objective of creative idea evaluation is not to winnow down the set of ideas into a single or very small number of solutions. The primary purpose of the refinement and evaluation step in concept generation is the identification of creative, feasible, yet still practical ideas. (Convergent thinking dominates this process.) The type of thinking used in refining the set of creative ideas is more focused than the divergent type of thinking that was used in generating creative ideas. Here we use convergent thinking to clarify concepts and arrive at ideas that are physically realizable. A quick way to do this is to group the ideas into three categories based on the judgment of the team as to their feasibility. Ideas that are feasible as they stand. (You would be happy to show them to your boss.) Ideas that may have potential after more thought or research are applied. (These ideas you would not want to show your boss.) Ideas that are very unfeasible and have no chance of becoming good solutions. Before discarding an idea, ask, "What about this idea makes it not feasible?" and "What would have to change for this idea to become feasible?" This type of examination of wacky ideas can lead to new insights into the design task. Checking concept ideas for feasibility is a critical step in the design process. Time is a valuable and limited resource the team cannot spend on developing design solutions with a low probability of success. It is difficult to choose the right time to eliminate early design concepts. If the time is too early, team members may not yet have enough information to determine the level of feasibility of some concepts. The more ambitious the design task, the more likely this is to be true. A valuable strategy used by successful teams is to document ideas and the rationale made for choosing to pursue them or not. When documentation is thorough, a team can take some risks in moving rapidly because they can retrace their steps through the documented design rationale.

An alternate strategy for classifying concepts is to group the ideas according to common engineering characteristics. It would make sense to use critical-to-quality engineering characteristics. There will always be a category for wild ideas. Next, the team examines each category of designs, one at a time. The team discusses the concepts within the class with the objective of seeing how they can be combined or rearranged into more completely developed solutions. Unlike the original brainstorming session, where emphasis was on quantity of ideas and discussion was minimized, here discussion and critical thought are encouraged. Team members can elaborate on ideas, piggyback on other ideas, or force-fit and combine ideas to create a new idea (Task 1). Then concepts are synthesized by combining ideas from the different categories (Task 2). Notice that the ideas that are combined to form a concept may come from any of the previous categories. Sometimes force-fitting results in further consolidation of the ideas (Task 3). The overall objective is to come out of this session with several well-developed design concepts. The above example is idealized. It uses only visual design elements to represent ideas, but mechanical design is more complex because functionality is the prime consideration in the generation of concepts. Also, aspects of form must be accommodated by the design concept. Please realize that this evaluation session is as important as the original meeting in which ideas were first generated. It should not be rushed. Typically, it will take two or three times as long as the first brainstorming session, but it is worth it.

Systematic Methods for Designing

These are systematic design methods because they involve a structured process for generating design solutions. Each will be presented in much greater detail in subsequent sections of this chapter. We mention them briefly here for the sake of completeness.

- Functional Decomposition and Synthesis Functional analysis is a logical approach for describing the transformation between the initial and final states of a system or device. The ability to describe function in terms of physical behavior or actions, rather than components, allows for a logical breakdown of a product in the most general way, which often leads to creative concepts of how to achieve the function.

- Morphological Analysis: The morphological chart approach to design generates alternatives from an understanding of the structure of necessary component parts. Entries from an atlas, directory, or one or more catalogs of components can then be identified and ordered in the prescribed configuration. The goal of the method is to achieve a nearly complete enumeration of all feasible solutions to a design problem. Often, the morphological method is used in conjunction with other generative methods like the functional decomposition and synthesis method

- Theory of Inventive Problem Solving TRIZ, the better-known Russian acronym for this method, is a creative problem-solving methodology especially tailored for scientific and engineering problems. Genrich Altshuller and coworkers in Russia started developing the method around 1940. From a study of over 1.5 million Russian patents they were able to deduce general characteristics of technical problems and recurring inventive principles.

- Axiomatic Design: Design models that claim legitimacy from the context of “first principles” include Suh’s texts on Axiomatic Design that articulate and explicate Design Independence and Information Axioms (i.e., maintain functional independence and minimize information content). Suh’s methods provide a means to translate a design task into functional requirements (the engineering equivalent of what the customer wants) and use those to identify design parameters, the physical components of the design. Suh’s principles lead to theorems and corollaries that help designers diagnose a candidate solution now represented as a matrix equation with function requirements and design parameters.

- Design Optimization: Many of the strongest and currently recognized design methods are actually searches of a design space using optimization strategies. These algorithms predict a design engineering performance once the design specifications have been set. This method is treating design as an engineering science problem and is effective at analyzing potential designs. There are many valid and verified optimization approaches to design. They range from single-objective and single-variable models to multi-objective, multi-variable models that are solved using different decompositions and sequences. Methods are deterministic, stochastic, and combinations of the two.

- Decision-Based Design is an advanced way of thinking about design. The DBD perspective on design differs from past design models that focus on problem solving in two major ways. The first is the incorporation of the customers' requirements as the driver of the process. The second is using the design outcomes (e.g., maximum profit, market share capture, or high-quality image) as the ultimate assessment of good designs.

Decision Making and Concept Selection

Some writers have described the engineering design process as a series of decisions carried out with less than adequate information. Certainly, creativity, the ability to acquire information, and the ability to combine physical principles into working concepts is critically important in making wise design decisions. So, too, are an understanding of the psychological influences on the decision maker, the nature of the trade-offs embodied in the selection of different options, and the uncertainty inherent in the alternatives. Moreover, the need to understand the principles behind good decision making is equally important to the business executive, the surgeon, or the military commander as it is to the engineering designer. Theory for decision making is rooted in many different academic disciplines, including pure mathematics, economics (macro and micro), psychology (cognitive and behavioral), probability, and many others. For example, the discipline of operations research contributed to decision theory. Operations research evolved from the work of a brilliant collection of British and American physicists, mathematicians, and engineers who used their technical talent to provide creative solutions to problems of military operations.

CONCEPT SELECTION

Concept selection is the process of evaluating concepts with respect to customer needs and other criteria, comparing the relative strengths and weaknesses of the concepts, and selecting one or more concepts for further investigation, testing, or development.

The method presented is also useful later in the development process when the team must select subsystem concepts, components, and production processes.

Overview of Methodology

• A two-stage concept selection methodology will be presented, although the first stage may suffice for simple design decisions.

• The first stage is called concept screening and the second stage is called concept scoring.

• Each is supported by a decision matrix which is used by the team to rate, rank, and select the best concept(s).

• Although the method is structured, the role of group insight to improve and combine concepts is emphasized.

Screening is a quick, approximate evaluation aimed at producing a few viable alternatives.

Scoring is a more careful analysis of these relatively few concepts in order to choose the single concept most likely to lead to product success.

Concept Screening

Concept screening is developed by Stuart Pugh in the 1980s and is often called Pugh concept selection. Purposes are to narrow the number of concepts quickly and to improve the concepts.

Step 1: Prepare the selection matrix.

- Can be done on paper, flip chart, or spreadsheet.
- Concepts and criteria are entered on the matrix. All concepts should be at the same level of detail (graphical and textual info) – no biases.

A simple one-page sketch of each concept greatly facilitates communication of the key features of the concept. If there are more than about 12 concepts, a multi vote method can be used to choose the dozen or so concepts to be evaluated with the screening matrix.

Step 2: Rate the Concepts

- A relative score of "better than" (+), "same as" (0) or "worse than" (-) is placed in each cell of the matrix to represent how each concept rates in comparison to the reference concept relative to the particular criterion. It's usually best to rate every concept on one criterion before moving to the next criterion.
- Objective metrics are best for rating concepts. E.g. No. of parts as approximation for assembly cost, No. of operations as approximation for ease of use, etc. Subjective metrics can be based on team consensus.
- Use hierarchical decomposition of selection criteria if necessary.

Step 3: Rank the Concepts

After rating all the concepts, the team sums the number of "better than", "same as", and "worse than" scores and enters the sum for each category in the lower rows of the matrix. A net score can be calculated, and the team can then rank-order the concepts. Obviously, the concepts with more pluses than minuses are ranked higher. Often at this point the team can identify one or two criteria which really seem to differentiate the concepts.

Step 4: Combine and Improve the Concepts

Having rated and ranked the concepts, the team should verify that the results make sense and then consider if there are ways to combine and improve certain concepts.

- Is there a generally good concept which is degraded by one bad feature? Can a minor modification improve the overall concept and yet preserve a distinction from the other concepts?
- Are there two concepts which can be combined to preserve the "better than" qualities while annulling the "worse than" qualities?

Combined and improved concepts are then added to the matrix, rated by the team, and ranked along with the original concepts in the next iteration.

Step 5: Select One or More Concepts

Based on the previous steps, the team will most likely develop a clear sense of which are the most promising concepts. The number of concepts selected for further review will be limited by team resources (personnel, money, and time). Having determined the concepts for further analysis, the team must clarify which issues need to be investigated further before a final selection can be made.

The team must also decide whether another round of concept screening will be performed or whether concept scoring will be applied next. If concept screening is not seen to provide sufficient resolution for the next step of evaluation and selection, then the concept-scoring stage with its weighted selection criteria and more detailed rating scheme would be used.

Step 6: Reflect on the Results and Process

All team members should be comfortable with the outcome. If someone is not in agreement with the decision of the team, then perhaps one or more important criteria are missing from the screening matrix, or a particular rating is in error, or at least is not clear.

Has a mistake been made? Do the results make sense to everyone on the team? Anything else need to be resolved?

Concept Scoring:

Is used when increased resolution will better differentiate among competing concepts. The team weighs the relative importance of the selection criteria and focuses on more refined comparisons with respect to each criterion.

Step 1: Prepare the Selection Matrix

Best to use a spreadsheet for this part.

– More detailed selection criteria may be added.

Importance weights are added to the matrix. This can be done by consensus or based on customer needs.

Step 2: Rate the Concepts

A scale of 1 to 5 is recommended: – Relative Performance Rating – Much worse than reference 1 – Worse than reference 2 – Same as reference 3 – Better than reference 4 – Much better than reference 5. Reference points need not be the same for all criteria.

Relative Performance	Rating
Much worse than reference	1
Worse than reference	2
Same as reference	3
Better than reference	4
Much better than reference	5

Step 3: Rank the Concepts

Once the ratings are entered for each concept, weighted scores are calculated by multiplying the raw scores by the criteria weight. The total score is the sum of the weighted scores. Finally, each concept is given a rank corresponding to its total score.

Step 4: Combine and Improve the Concepts

Some of the most creative refinements and improvements occur during the concept selection process as the team realizes the inherent strengths and weaknesses of certain features of the product concepts. Don’t have tunnel vision … keep an open mind.

Step 5: Select One or More Concepts

The final selection is not simply a question of choosing the concept that achieves the highest ranking after the first pass through the process. The team should explore this initial evaluation by conducting a sensitivity analysis. Weights and ratings can be varied to determine their effect on the ranking. Uncertainty about a particular rating can be assessed and may affect the choice.

Step 6: Reflect on the Results and the Process

This is the “point of no return” for the concept development process, so everyone on the team should feel comfortable that all of the relevant issues have been discussed and that the selected concept(s) have greatest potential to satisfy customers and be economically successful. A useful reality check is to review concepts that have been eliminated. Has a mistake been made? Did the concept selection method facilitate team decision making? How can the method be modified to improve team performance?

EMBODIMENT DESIGN

We have now brought the engineering design process to the point where a set of concepts has been generated and evaluated to produce a single concept or small set of concepts for further development. It may be that some of the major dimensions have been established roughly, and the major components and materials have been tentatively selected. Some of the performance characteristics and design parameters have been identified as being critical to quality (CTQ). At this point a feasibility design review is usually held to determine whether the design concept looks promising enough that resources should be committed to develop the design further. The next phase of the design process is often called embodiment design. It is the phase where the design concept is invested with physical form, where we “put meat on the bones.” We have divided the embodiment phase of design into three activities

- Product architecture— determining the arrangement of the physical elements of the design into groupings, called modules
- Configuration design—the design of special-purpose parts and the selection of standard components, like pumps or motors

  Parametric design— determining the exact values, dimensions, or tolerances of the components or component features that are deemed critical-to-quality.

PRODUCT ARCHITECTURE

- Product architecture is the arrangement of the physical elements of a product to carry out its required functions.
- The product architecture begins to emerge in the conceptual design phase from such things as diagrams of functions, rough sketches of concepts, and perhaps a proof-of-concept model.
- However, it is in the embodiment design phase that the layout and architecture of the product must be established by defining the basic building blocks of the product and their interfaces.

MODULES

- The physical building blocks that the product is organized into are usually called *modules*. Other terms are subsystem, subassembly, cluster, or chunk.
- Each module is made up of a collection of components that carry out functions. The architecture of the product is given by the relationships among the components in the product and the functions the product performs.
- There are two entirely opposite styles of product architecture:
    - Modular
    - Integral

MODULAR ARCHITECTURE

- In a modular architecture, each module implements only one or a few functions, and the interactions between modules are well defined.

- An example would be an oscilloscope, where different measurement functions are obtained by plugging in different modules, or a personal computer where different functionality can be achieved with an external mass storage device or adding special-purpose drives.

INTEGRAL ARCHITECTURE

- In an integral architecture the implementation of functions is accomplished by only one or a few modules. In integral product architectures, components perform multiple functions. This reduces the number of components, generally decreasing cost unless the integral architecture is obtained at the expense of extreme part complexity.

A simple example is the crowbar, where a single part provides both the functions of providing leverage and acting as a handle.

INTERFACES

- The interfaces between modules are critical to successful product functioning.
- These are often the sites for corrosion and wear. Unless interfaces are designed properly, they can cause residual stresses, unplanned deflections, and vibration.
- Examples of interfaces are the crankshaft of an engine connected with a transmission or the connection between a computer monitor and the CPU. Interfaces should be designed so as to be as simple and stable as possible.
- The personal computer is an outstanding example of the use of standard interfaces. PCs can be customized, module by module, from parts supplied by many different suppliers. A USB port can attach a variety of drives, printers, and PDAs to any computer.

STEPS IN DEVELOPING PRODUCT ARCHITECTURE

- **Create a schematic diagram of the product**.
  - The process of developing the product architecture will be. It focuses on a machine for making plastic three dimensional parts quickly and directly from computer-aided design (CAD) files.

  - **Cluster the elements of the schematic**.
  - The second step of setting product architecture is to create groups of elements in the schematic. The purpose of this step is to arrive at an arrangement of modules or clusters by assigning each design element to a module.
  - Some of the reasons for clustering elements include requiring close geometric relationship or precise location, elements that can share a function or an interface, the desire to outsource part of the design, and the portability of interfaces
- **Create a rough geometric layout.**
  - Making a geometric layout allows the designer to investigate whether there is likely to be geometrical, thermal, or electrical interference between elements and modules.
  - A trial layout positions module in a possible physical configuration for the final design. For some problems a two-dimensional drawing is adequate, while for others a three-dimensional model (either physical or computer model) is required. Creating

a geometric layout forces the team to decide whether the geometric interfaces between the modules are feasible

- **Identify the interactions between modules.**
  - The most critical task in determining a product's architecture is accurately modeling the interactions between the modules and setting the performance characteristics for the modules. At the conclusion of the embodiment design phase of the product development process, each product module must be described in complete detail.
  - The documentation on each module should include:
  - Functional requirements
  - Drawings or sketches of the module and its component parts
  - Preliminary component selection for the module
  - Detailed description of placement within the product

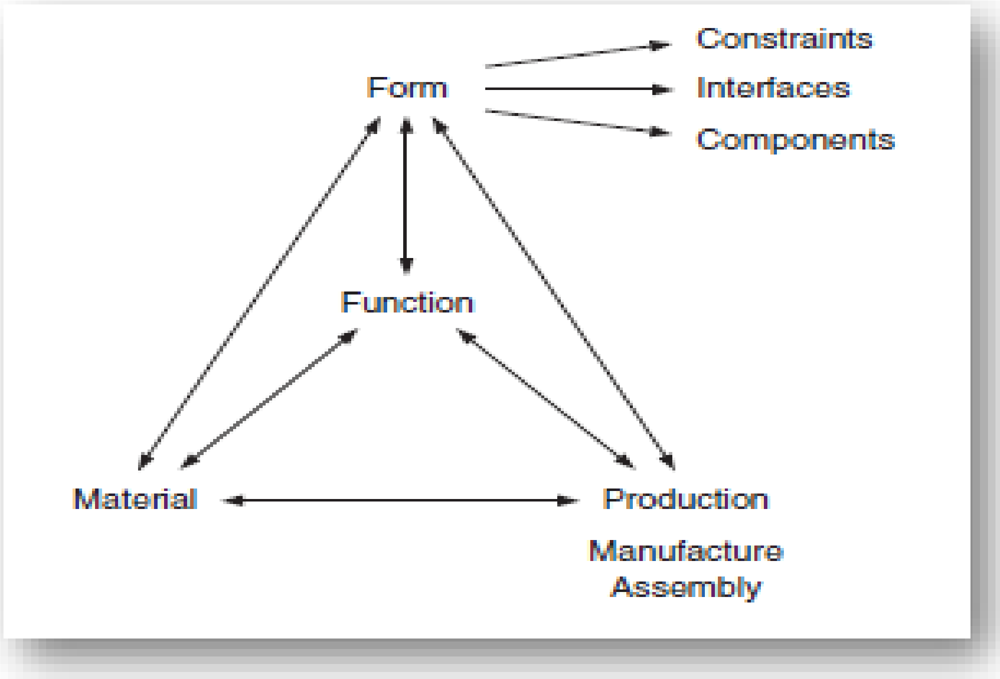
CONFIGURATION DESIGN

- In configuration design we establish the shape and general dimensions of components. Exact dimensions and tolerances are established in parametric design.
- The term *component* is used in the generic sense to include special-purpose parts, standard parts, and standard assemblies.
- A part is a designed object that has no assembly operations in its manufacture. A part is characterized by its geometric *features* such holes, slots, walls, ribs, projections, fillets, and chamfers.
- The *arrangement of features* includes both the location and orientation of the geometric features.

- A *standard part* is one that has a generic function and is manufactured routinely without regard to a particular product. Examples are bolts, washers, rivets, and I-beams. A *special-purpose part* is designed and manufactured for a specific purpose in a specific product line.
- An *assembly* is a collection of two or more parts.
- A *subassembly* is an assembly that is included within another assembly or subassembly.
- A *standard assembly* is an assembly or subassembly that has a generic function and is manufactured routinely. Examples are electric motors, pumps, and gearboxes.

In starting configuration design, we should follow these steps:

- Review the product design specification and any specifications developed for the particular subassembly to which the component belongs.
- Establish the spatial constraints that pertain to the product or the subassembly being designed. Most of these will have been set by the product architecture. In addition to physical spatial constraints, consider the constraints of a human working with the product and constraints that pertain to the product's lifecycle, such as the need to provide access for maintenance or repair or to dismantle it for recycling.
- Create and refine the interfaces or connections between components. Again, the product architecture should give much guidance in this respect. Much design effort occurs at the connections between components, because this is the location where failure often occurs. Identify and give special attention to the interfaces that transfer the most critical functions.
- Before spending much time on the design, answer the following questions: Can the part be eliminated or combined with another part? Studies of design for manufacture (DFM) show that it is almost always less costly to make and assemble fewer, more complex parts than it is to design with a higher part count.
- Can a standard part or subassembly be used? While a standard part is generally less costly than a special-purpose part, two standard parts may not be less costly than one special-purpose part that replaces them.
- Schematic illustrating the close interrelationship between function and form and, in turn, their dependence on the material and the method of production.



PARAMETRIC DESIGN

- In parametric design the attributes of components identified in configuration design become the design variables for parametric design.
- A *design variable* is an attribute of a part whose value is under the control of the designer. This typically is a dimension or a tolerance, but it may be a material, heat treatment, or surface finish applied to the part. This aspect of design is much more analytical than conceptual or configuration design.
- The objective of parametric design is to set values for the design variables that will produce the best possible design considering both performance and cost (as manifested by manufacturability).

A systematic parametric design takes place in five steps:

- *Step 1: Formulate the parametric design problem.* The designer should have a clear understanding of the function or functions that the component to be designed must deliver. This information should be traceable back to the PDS and the product architecture.

- *Step 2: Generate alternative designs.* Different values for the design variables are chosen to produce different candidate designs. Remember, the alternative configurations were narrowed down to a single selection in configuration design. Now, we are determining the best dimensions or tolerances for the critical-to-quality aspects of that configuration. The values of the DVs come from your or the company's experience, or from industry standards or practice

- *Step 3: Analyze the alternative designs.* Now we predict the performance of each of the alternative designs using either analytical or experimental methods. Each of the designs is checked to see that it satisfies every performance constraint and expectation. These designs are identified as *feasible designs.*
- *Step 4: Evaluate the results of the analyses.* All the feasible designs are evaluated to determine which one is best using the solution evaluation parameters. Often, a key performance characteristic is chosen as an *objective function, and* optimization methods are used to either maximize or minimize this value.

DETAIL DESIGN

The activities in the detail design phase are as follows:

- Make/buy decision

Even before the design of all components is completed and the drawings finalized, meetings are held on deciding whether to make a component in-house or to buy it from an external supplier. This decision will be made chiefly on the basis of cost and manufacturing capacity, with due consideration given to issues of quality and reliability of delivery of components. Sometimes the decision to manufacture a critical component in-house is based solely on the need to protect trade secrets concerned with a critical manufacturing process. An important reason for making this decision early is so you can bring the supplier into the design effort as an extended team member.

- Complete the selection and sizing of components

While most of the selection and sizing of components occurs in embodiment design, especially for those components with parameters deemed to be critical-to-quality, some components may not yet have been selected or designed. These may be standard components that will be purchased from external suppliers or routine standard parts like fasteners. Or, there may be a critical component for which you have been waiting for test data or FEA analysis results. Regardless of the reason, it is necessary to complete these activities before the design can be complete. If the product design is at all complex, it most likely will be necessary to impose a design freeze at some point prior to completion. This means that beyond a certain point in time no changes to the design will be permitted unless they go through a formal review by a design control board. This is necessary to prevent the human tendency to continually make slight improvements, which unless controlled by some external means results in the job never actually being completed. With a design freeze, only those last-minute changes that truly affect performance, safety, or cost are approved.

- Complete engineering drawings

A major task in the detail design phase is to complete the engineering drawings. As each component, subassembly, and assembly is designed, it is documented completely with drawings of individual parts are usually called detail drawings. These show the geometric features, dimensions, and tolerances of the parts. Sometimes special instructions for processing the part in manufacture, like heat treating or finishing steps, are included on the drawing. Assembly drawings show how the parts are put together to create the product or system.

- Complete the bill of materials

The bill of materials (BOM) or parts list is a list of each individual component in the product. It is used in planning for manufacture and in determining the best estimate of product cost.

- Revise the product design specification

When the Product Design Specification was introduced, it was emphasized that the PDS is a "living document" that changes as the design team gains more knowledge about the design of the product. In detail design the PDS should be updated to include all current requirements that the design must meet. We need to distinguish between the part specification and the product design specification. For individual parts the drawing and the specification are often the same document. The specification contains information on the technical performance of the part, its dimensions, test requirements, materials requirements, reliability requirement, design life, packaging requirement, and marking for shipment. The part specification should be sufficiently detailed to avoid confusion as to what is expected from the supplier.

- Complete verification prototype testing

Once the design is finalized, a beta-prototype is built and verification tested to ensure that the design meets the PDS and that it is safe and reliable. The beta-prototypes are made with the same materials and manufacturing processes as the product but not necessarily from the actual production line. Later, before product launch, actual products from the production line will be tested. Depending on the complexity of the product, the verification testing may simply be to run the product during an expected duty cycle and under overload conditions, or it may be a series of statistically planned tests.

- Final cost estimate

The detail drawings allow the determination of final cost estimates, since knowledge of the material, the dimensions, tolerances, and finish of each part are needed to determine manufacturing cost. To make these calculations a bill of materials is utilized. Cost analysis also needs specific information about the particular machines and process steps that will be used to make each part. Note that cost estimates have been made at each step of the product design process with successively smaller margins for error.

- Prepare design project report

A design project report usually is written at the conclusion of a project to describe the tasks undertaken and to discuss the design in detail. This is a vital document for passing on design know-how to a subsequent design team engaged in a product redesign project. Also, a design project report may be an important document if the product becomes involved in either product liability or patent litigation.

- Final design review

Many formal meetings or reviews will have preceded the final design review. These include an initial product concept meeting to begin the establishment of the PDS, a review at the end of conceptual design to decide whether to proceed with full-scale product development, and a review after embodiment design to decide whether to move into detail design. The latter may take the form of detailed partial reviews (meetings) to decide important issues like design for manufacturing, quality issues, reliability, safety, or preliminary cost estimates. However, the final design review is the most structured and comprehensive of the reviews. The final design review results in a decision by management on whether the product design is ready for production, and the major financial commitment that this entails.

- Release design to manufacturing

The release of the product design to manufacturing ends the main activity of the design personnel on that product. The release may be done unconditionally, or under pressure to introduce a new product it may be done conditionally. In the latter case, manufacturing moves ahead to develop tooling while design works on an accelerated schedule to fi x some design deficiencies. The increasing use of the concurrent engineering approach to minimize the product development time blurs the boundary between detail design and manufacturing. It is common to release the design to manufacturing in two or three “waves,” with those designs that have the longest lead time for designing and making tooling being released first.

MODELLING AND SIMULATION

Evaluation of the performance of parts, products, and systems is a central activity of engineers and engineering designers. Analyzing performance is a crucial step in the earliest stages of product development (i.e., conceptual design) and continues to be used at a more detailed level in embodiment design whenever a choice must be made among options. Our engineering courses teach first principles in subjects like statics, dynamics, and mechanics of materials, fluids, and thermodynamics by describing a physical system and its immediate environment in a complex word problem that students learn to solve using a variety of analytical, logical, mathematical, and empirical methods. This explains why engineering students view making design decisions as problem solving. In their engineering science courses students are typically given all the detail necessary to translate a decision-making scenario into an evaluation problem. However, in design courses students are faced with making decisions on open-ended problems where they themselves must determine which details about the system are necessary. This process amounts to setting up models and using them for evaluation purposes. Efficient analysis of products and systems requires descriptions of each design or system option that are just detailed enough that performance measures of interest can be accurately calculated. This description required for analysis is called a model. The model can include a representation of the physical aspects of the product or system (i.e., a sketch or geometric model), constraints on the design detail to be modeled, and mathematical equations that govern its behavior. Since models can include several different types of information, it is important for a designer to be aware of the variety possible in modeling. The first type of model one thinks of is a physical model made of plastic or wood or other easy-to-work materials. It may be a representation frozen in time or it can have joints and subsystems that mimic the actual motion of the design in a variety of use conditions. Models can also be design sketches, mechanical drawings done by hand, or one of a variety of computer-aided design (CAD) representations. A model can also exist as equations that describe characteristics of the product or system of interest. These models are called mathematical or analytical models. Lastly, a model can be a combination of both geometric and functional representations. The value designers can get out of a model depends on the skill with which it has been created and the time available to analyze the model. Mathematical models are created to explore a design space by solving the equations for a variety of input variables to obtain a set of outputs.

Simulation is the exploration of a model by varying the system inputs. Often this is done with a computer based mathematical model, but sometimes the behavior of a part or system may be too complex to model analytically. In this type of situation, a designer must rely on testing a physical prototype to demonstrate the behavior and collect data points under a variety of conditions that mimic the behavior. Simulation with physical models is resource-intensive. Experimentation with physical prototypes is also unworkable when a designer needs to evaluate candidate design concepts before the embodiment design is complete.

Part II
INTRODUCTION

INTRODUCTION TO ADDITIVE MANUFACTURING

Additive Manufacturing refers to a process by which digital 3D design data is used to build up a component in layers by depositing material. The term "3D printing" is increasingly used as a synonym for Additive Manufacturing. However, the latter is more accurate in that it describes a professional production technique which is clearly distinguished from conventional methods of material removal. Instead of milling a workpiece from solid block, for example, Additive Manufacturing builds up components layer by layer using materials which are available in fine powder form. A range of different metals, plastics and composite materials may be used.

The technology has especially been applied in conjunction with Rapid Prototyping - the construction of illustrative and functional prototypes. Additive Manufacturing is now being used increasingly in Series Production. It gives Original Equipment Manufacturers (OEMs) in the most varied sectors of industry the opportunity to create a distinctive profile for themselves based on new customer benefits, cost-saving potential and the ability to meet sustainability goals.

BENEFITS OF AM:

The strengths of Additive Manufacturing lie in those areas where conventional manufacturing reaches its limitations. The technology is of interest where a new approach to design and manufacturing is required so as to come up with solutions. It enables a design-driven manufacturing process - where design determines production and not the other way around. What is more, Additive Manufacturing allows for highly complex structures which can still be extremely light and stable. It provides a high degree of design freedom, the optimization and integration of functional features, the manufacture of small batch sizes at reasonable unit costs and a high degree of product customization even in serial production.

FUNCTIONAL PRINCIPLE OF AM:

The system starts by applying a thin layer of the powder material to the building platform. A powerful laser beam then fuses the powder at exactly the points defined by the computer-generated component design data. The platform is then lowered and another layer of powder is applied. Once again, the material is fused so as to bond with the layer below at the predefined points. Depending on the material used, components can be manufactured using stereolithography, laser sintering or 3D printing.

TYPES OF AM PROCESSESS:

1. VAT Polymerization
2. Binder jetting
3. Sheet lamination
4. Material jetting
5. Direct energy Deposition
6. Power Bed fusion
7. Material extrusion

STEPS TO MAKE A PRODUCT USING AM TECHNOLOGY:

1. CAD/ SCANNING

Producing a digital model is the first step in the additive manufacturing process. The most common method for producing a digital model is computer aided design (CAD). There are a large range of free and professional CAD programs that are compatible with additive manufacture. Reverse engineering can also be used to generate a digital model via 3D scanning. There are several design considerations that must be evaluated when designing for additive manufacturing. These generally focus on feature geometry limitations and support or escape hole requirements and vary by technology.

2. STL conversion and file manipulation:

A critical stage in the additive manufacturing process that varies from traditional manufacturing methodology is the requirement to convert a CAD model into an STL (stereolithography) file. STL uses triangles (polygons) to describe the surfaces of an object. A guide on how to convert a CAD model to an STL file can be found here. There are several model limitations that should be considered before converting a model to an STL file including physical size, water tightness and polygon count.

Once a STL file has been generated the file is imported into a slicer program. This program takes the STL file and converts it into G-code. G-code is a numerical control (NC) programming language. It is used in computer-aided manufacturing (CAM) to control automated machine tools (including CNC machines and 3D printers). The slicer program also allows the designer to customise the build parameters including support, layer height, and part orientation .Using the slicer program Preform to insert support and prepare a model for printing

3. Printing

3D printing machines often comprise of many small and intricate parts so correct maintenance and calibration is critical to produce accurate prints. At this stage the print material is also loaded into the printer. The raw materials used in additive manufacturing often have a limited shelf life and require careful handling. While some processes offer the ability to recycle excess build material, repeated reuse can result in a reduction in material properties if not replaced regularly.

Most additive manufacturing machines do not need to be monitored after the print has begun. The machine will follow an automated process and issues generally only arise when the machine runs out of material or there is an error in the software. A explanation on how each of the different additive manufacturing printers produce parts can be found here.

4. Removal of prints

For some additive manufacturing technologies removal of the print is as simple as separating the printed part from the build platform. For other more industrial 3D printing methods the removal of a print is a highly technical process involving precise extraction of the print while it is still encased in the build material or attached to the build plate. These methods require complicated removal procedures and highly skilled machine operators along with safety equipment and controlled environments. Removing support from an SLA print

5. Post processing

Post processing procedures again vary by printer technology. SLA requires a component to cure under UV before handling, metal parts often need to be stress relieved in an oven while FDM parts can be handled right away. For technologies that utilize support, this is also removed at the post processing stage. Most 3D printing materials are able to be sanded and other post processing techniques including tumbling, high pressure air cleaning, polishing and colouring are implemented to prepare a print for end use.

LITERATURE REVIEW

CAD DESIGNS

Computer-Aided designing is the use of the computer system to aid in the creation, modification, analysis or optimization of a design. A CAD software is used to increase the productivity of the designer, improve communications through documentation, and to create a data base for manufacturing. CAD output is often in the form of electronic files for print, machining, or other manufacturing operation. Its use in designing mechanical object is called Mechanical design automation or computer aided drafting (CAD). However, it evolves more than its shapes. It either uses a vector based graphic to depict the object of traditional drafting or may produce raster graphics showing the overall appearance of the designed objects. IT can be used to design curves and figures in 2-D or in 3-D too. It is used in drawing model of the objects by additive manufacturing too. However, different process to produce a product shape is scanning too.

SCANNED MODELS

Under this category of producing a model of the object by scanning the object with the help of an 3D scanner (laser scanning) which scan the object to its best accuracy and precision and at regular interval it need proper calibration which can be done as follows:

- Verify the scanhead geometry and alignment, and adjust if necessary.
- Take a large number of measurements and generate compensations for always present but subtle optical and geometric imperfections.
- Verify the newly calibrated scanhead with certified and NIST-traceable objects, such as gauge blocks and balls bars
- Create a certificate of scanhead calibration with accuracy results

DIFFERENT PARAMETERS THAT EFFECT THE 3-D SCANNING PROCESS

1. SPEED OF SCANNING

2. TEMPERATURE OF THE WORKING ENVIRONMENT
3. INTENSITY OF LIGHT
4. COMPLEXITY
5. SIZE

SOFTWARE

1. 3DUNDERWORLD SLS - OPEN SOURCE
2. DIY 3D scanner based on structured light and stereo vision in Python language
3. SLStudio -- Open Source Real Time Structured Light

ABOUT THE SOFTWARE USED FOR COMPARISON IN THE REPORT

Geomagic is the professional engineering software brand o6D Systems. The brand began when Geomagic Inc., a software company based in Morrisville, North Carolina, was acquired by 3D Systems in February 2013[1] and combined with that company's other software businesses (namely Rapidform and Alibre). Geomagic was founded in 1997 by Ling Fu and Herbert Edelsbrunner

Geomagic-branded software products are focused on computer-aided design, with an emphasis on 3D scanning and other non- traditional design methodologies, such as voxel-based modeling with haptic input. 3D Systems also markets 3D quality inspection software as well as 3D scanners under the Geomagic brand.

Geomagic Products

3D Scanning Systems

Geomagic Capture is an integrated system consisting of a blue LED structured-light 3D scanner and one of several pieces of application-specific software. The systems are marketed for use as scan-based design tools, wherein a physical object is 3D scanned and then converted into a 3D CAD model, or inspection tools, wherein a physical object is scanned and then dimensionally verified by comparing to a nominal 3D CAD model.

3D Design Software

Geomagic Design is a mechanical Computer-Aided Design software, with an emphasis on the design of mechanical systems and assemblies. Geomagic Freeform and Sculpt software are cloud-based modeling software packages, and are bundled with 3D Systems' Touch haptic devices which interface with the software to deliver force-feedback to the user. Geomagic Design X, Design Direct, Studio and Wrap are software products that offer different workflows for creating manufacturing-ready 3D models, including Solid modeling and NURBS surfacing.

3D Inspection and Metrology Software

Geomagic Qualify and Geomagic Verify focus on delivering measurement, comparison and reporting software tools for first-article and automated inspection processes. Data from point cloud and 3D scanners and Coordinate Measuring Machines (CMMs) can be used, as well as CAD data imported into the system.

Applications

Having a robust inspection process to improve quality control is critical in today's world of manufacturing. With accurate 3D scanning and inspection analysis, companies can reduce iterations/tuning loops and quickly derive the proper corrective action without slowing down their time to market goals. The faster this information is given, the faster the decisions and modifications can be made.

Quality Inspection using 3D scanning has made Inspection easier and faster like:

1. Aerospace & IGT industries
2. Automotive Industries
3. Product Development Sections

being few examples.

Conclusion

With continuous advances in optical inspection technology yielding 3D scanners that are today capable of stunning speed and accuracy, a growing number of companies are including this technology in their first article inspection (FAI) procedures. The key benefit of using an instrument that rapidly collects millions of data points is that all part/assembly dimensions can be measured in far less time; and in the case of CT scanning, internal measurements can be taken without destroying the parts.

Traditionally, FAI utilizes coordinate measuring machines (CMMs). The majority of CMMs implement a touch probe to acquire points one at a time. There has been progress in recent years with some tactile probes now moving to allow streaming of points but most CMMs still take only one measurement/point every few seconds.

The most common methods of collecting noncontact 3D measurements are: handheld laser scanners with or without a portable CMM arm, computed topography (CT), structured blue/white light scanners, and CMM mounted scanners. The best choice for any FAI scenario will depend on the accuracy required, size of the parts, and whether internal features must be captured as well. For example, since a handheld scanner is capable of capturing 3D measurements from objects of almost any shape, it would be a good choice for measuring mid-size consumer products like sports equipment and furniture, whereas a CMM scanner is a better choice for objects requiring higher accuracy, such as turbine blades. On the other hand, CT scanning, with its ability to nondestructively measure internal components, would be the best choice for inspecting wall thickness of HVAC tubing or medical devices with critical internal geometry.

There are a number of industry approved inspection software packages that are able to analyze the high-density point cloud data or stereolithography (STL) data from the scanners. Some companies may require specific CMM software to analyze the data. For these cases, there are various software packages that will act as a “virtual CMM” and are programmed to measure the STL “virtual part” and generate a report exactly as if it had been probed on a CMM.

FAI using scan data can be carried out by using a 2D print of the part for comparison, but a much more comprehensive inspection can be done if a 3D CAD file for the part/assembly is available. A CAD model is almost essential if any geometric dimensioning and tolerancing (GD&T) operations are required.

After the measurements are taken, the data can be first aligned using “best fit” algorithms or “N-Point” alignment, followed by a more accurate alignment created using datum features. Once aligned, a number of inspections operations are available:

1. Color deviation map (“heat chart”) of the entire scanned surface area. Data above the CAD surface moves towards red in the color spectrum while data below the CAD surface moves toward blue. Alternately, this color chart can be presented as a “go/no go” image. In addition, points of interest can be clicked on to check their deviation, which is shown with a flyout. Wall thickness can be automatically calculated and displayed as a separate heat chart.
2. 2D cross-sections can be taken at any position/angle, compared to the CAD file, and presented with “whisker-plots” colored to indicate their deviation. Here again, points may be clicked and their deviation displayed.
3. 2D cross-sections can be selected and analyzed with 2D dimensions, including the use of theoretical points and lines.
4. Geometric forms such as cylinders/planes/circles can be extracted from the CAD file, created automatically from the scan data, and compared.
5. All standard GD&T operations can be carried out on the data set. Most applications require the use of a CAD model.

All FAI results can be saved in a custom report in various formats, usually PDF, including full statistical analysis of the 2D and 3D surface deviations.

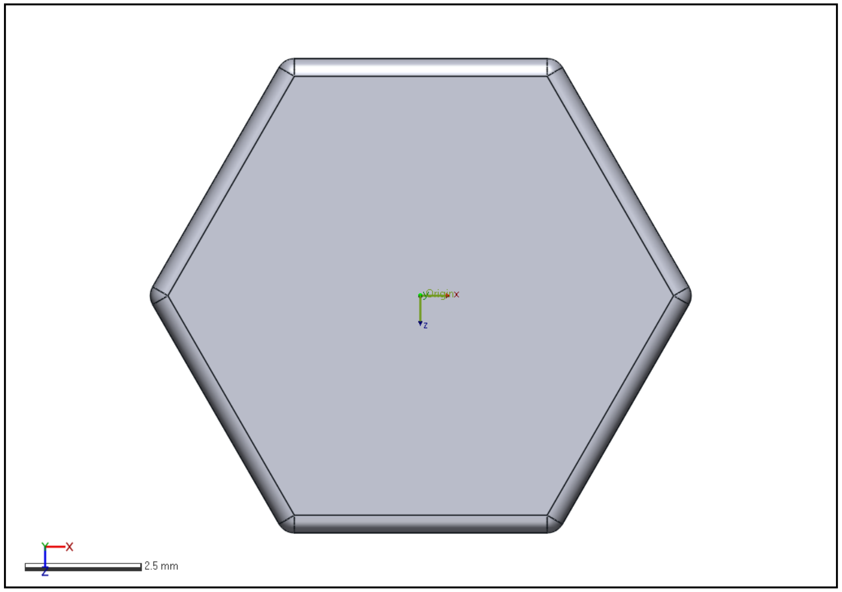
If the same part is to be re-measured at a later date, then the same reports can be created with little effort, including batch analysis of multiple data files of the same type. The ability to generate the same reports with new data also enables the use of trend analysis for forecasting future problems.

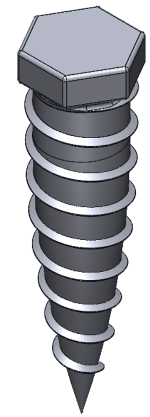
FAI is poised to enter a new era where even the smallest deviation from an original design can be detected and quickly corrected. Three-dimensional scanning offers a clear win-win opportunity for manufacturers: save time and improve quality while delivering a better product to your customer.

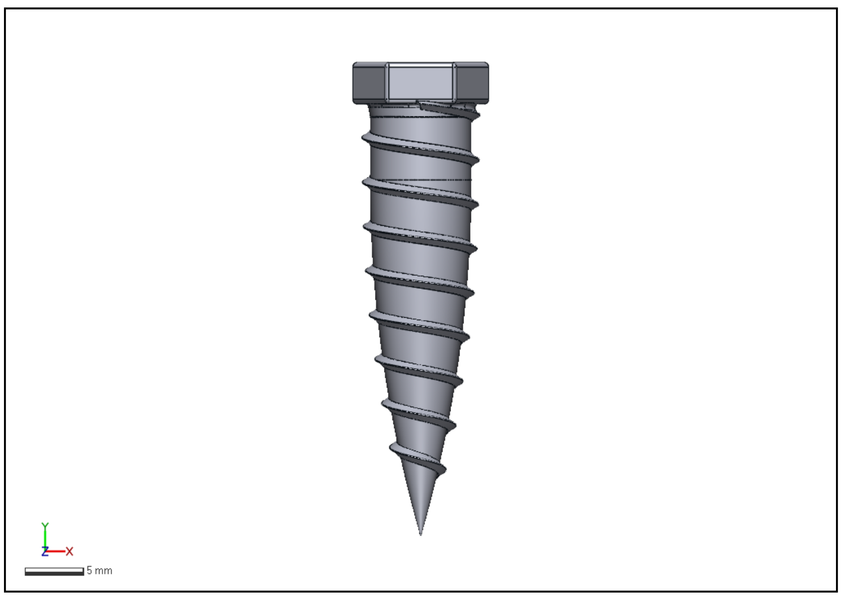
REPORT

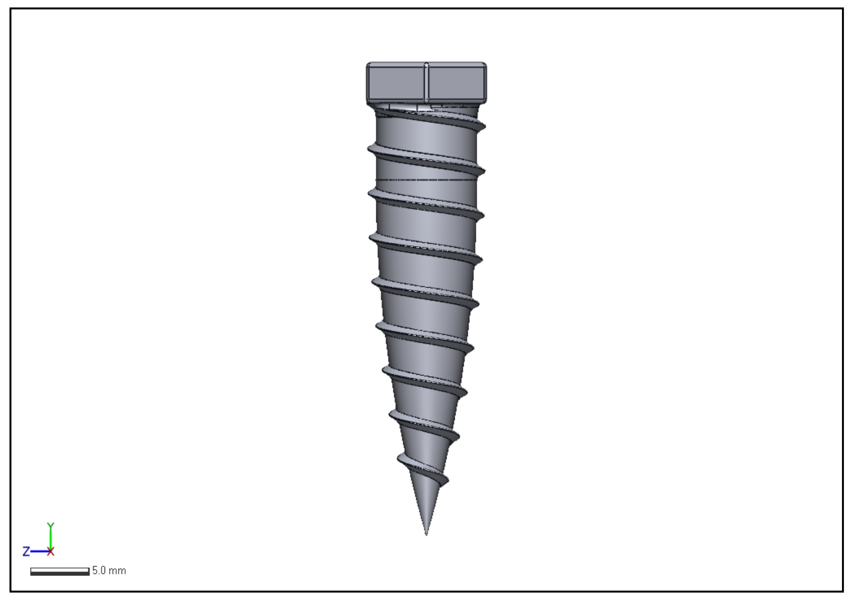
Product Name	Custom Screw
Part Name	N/A
Part Number	10
Department	Mechanical Engineering
Inspector	Ismael, Udit, Yash
Date	Dec 18, 2017
Unit	mm

Result Data - 1 :   Reference Data   -   Part1



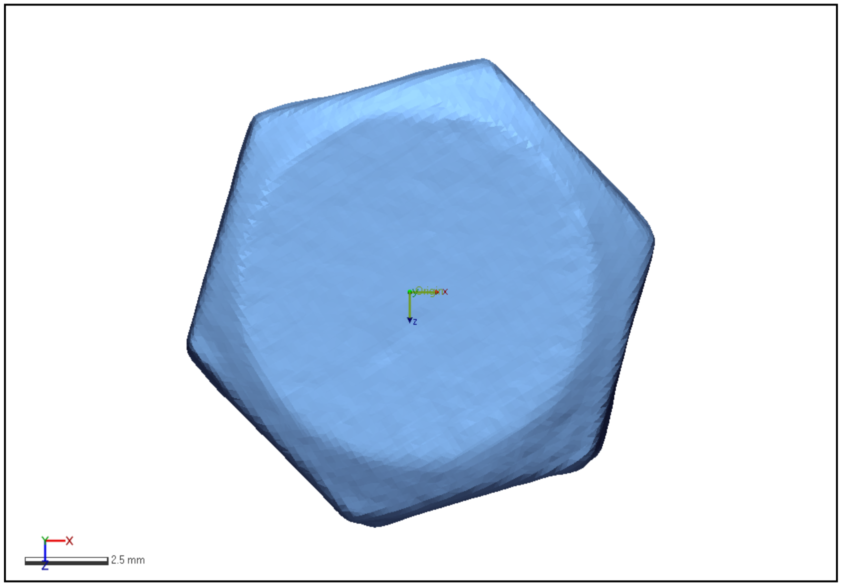


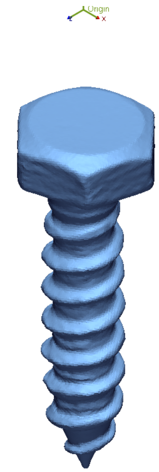


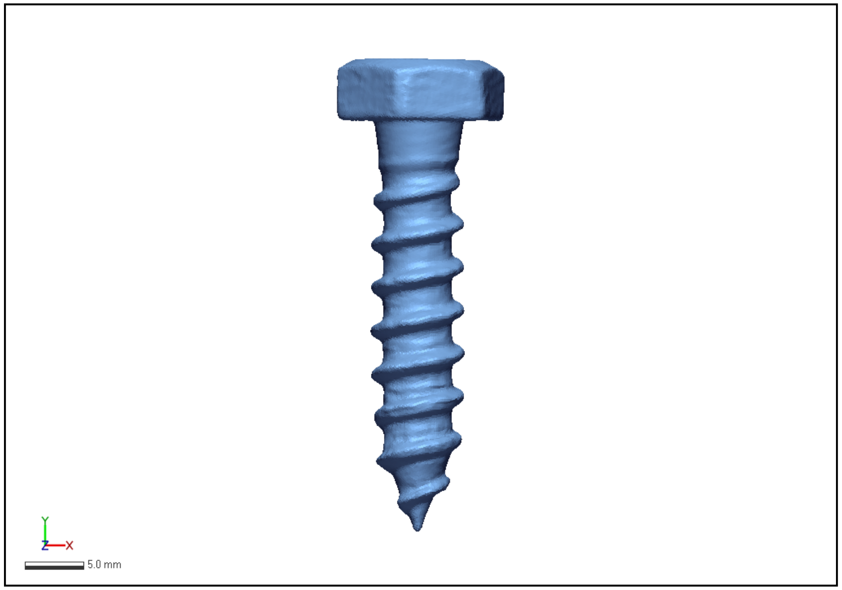


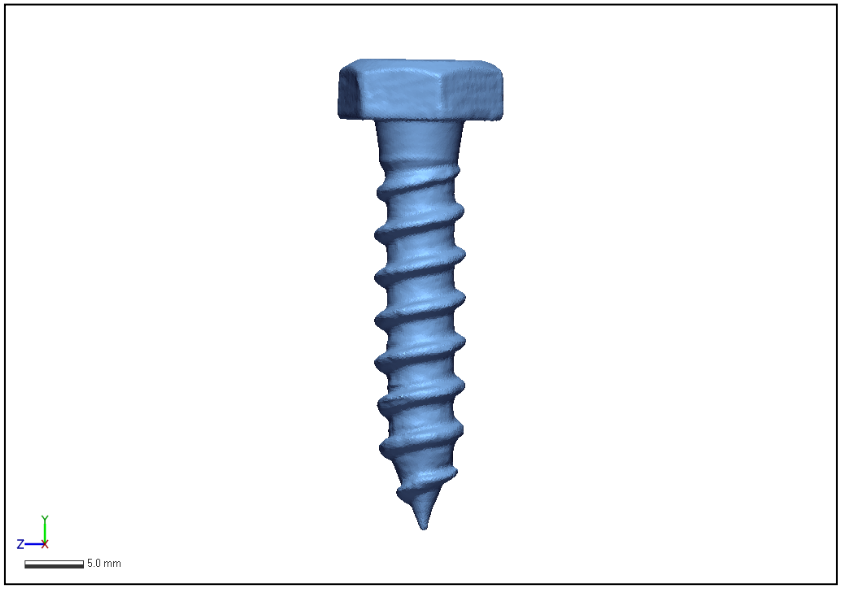
Product Name	[Product Name]		Department	[Department]		Date	Dec 18, 2017
Part Name	[Part Name]		Inspector	[Inspector]		Unit	mm

Result Data - 1 : Measured Data - Screw







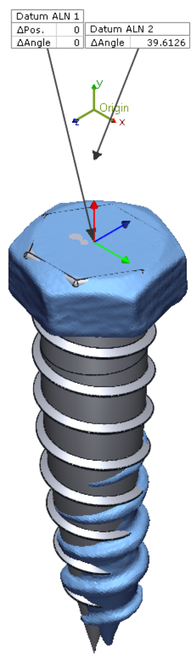


Product Name	[Product Name]
Part Name	[Part Name]

Department	[Department]
Inspector	[Inspector]

Date	Dec 18, 2017
Unit	mm

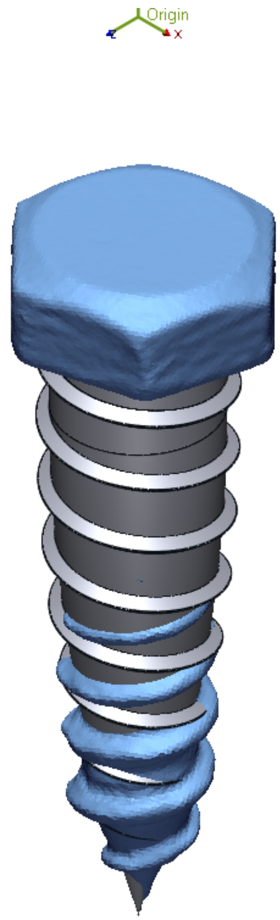
Result Data - 1 : Datum Alignment1

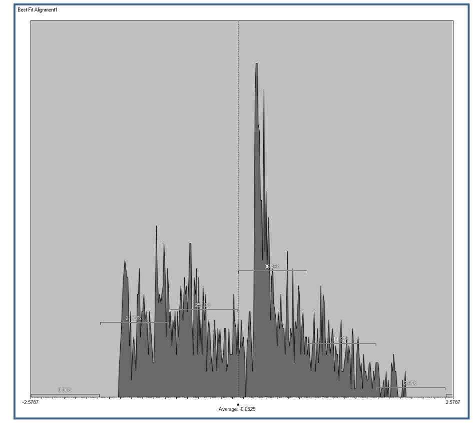


Name	Result Name	Dev.	ΔAngle	ΔPos.
Datum ALN 1	Result Data - 1	0	0	0
Datum ALN 2	Result Data - 1	39.6126	39.6126	

Product Name	[Product Name]	Department	[Department]	Date	Dec 18, 2017
Part Name	[Part Name]	Inspector	[Inspector]	Unit	mm

Result Data - 1 :   Best Fit Alignment1

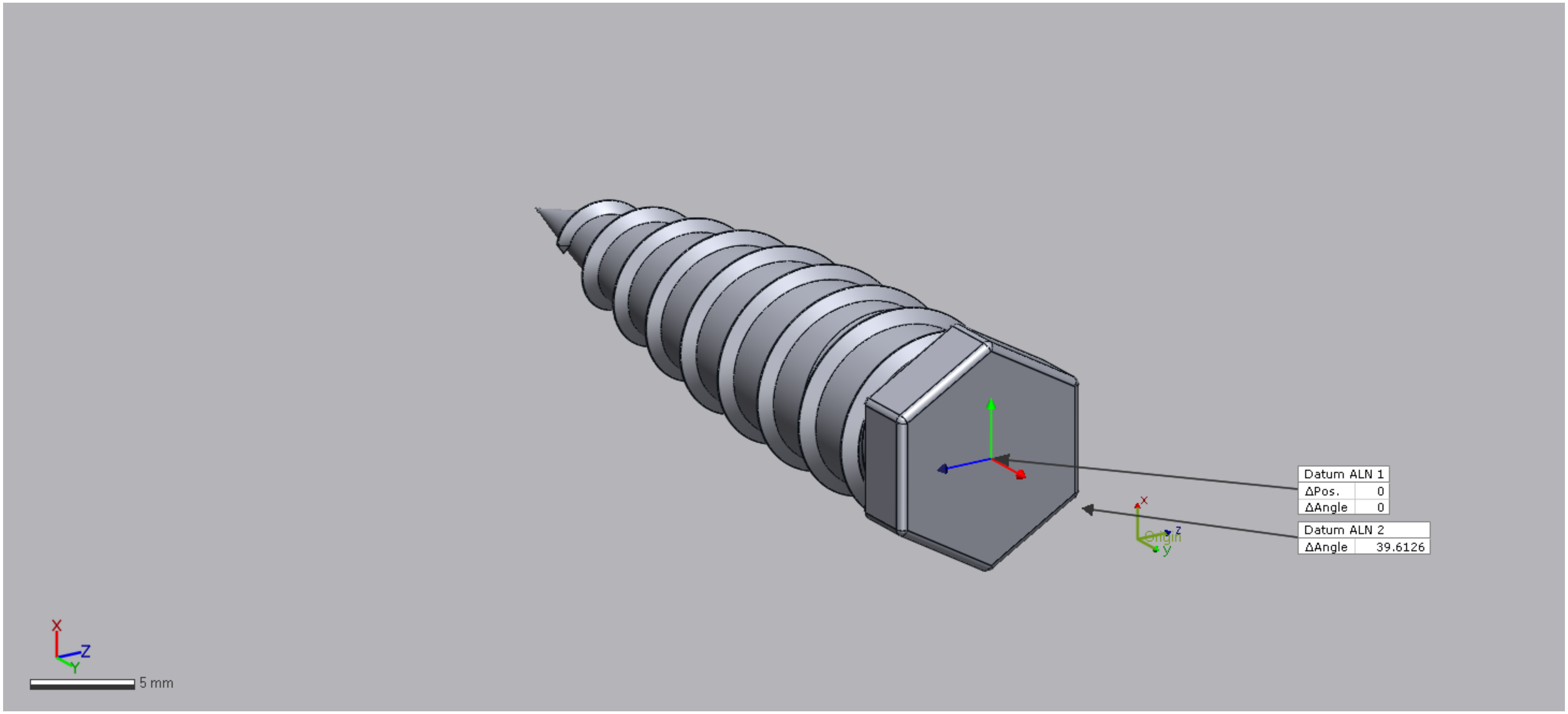




Min.	-1.5
Max.	1.9857
Avg.	-0.0525
RMS	0.8437
Std. Dev.	0.8421
Var.	0.7091
+Avg.	0.6324
-Avg.	-0.801

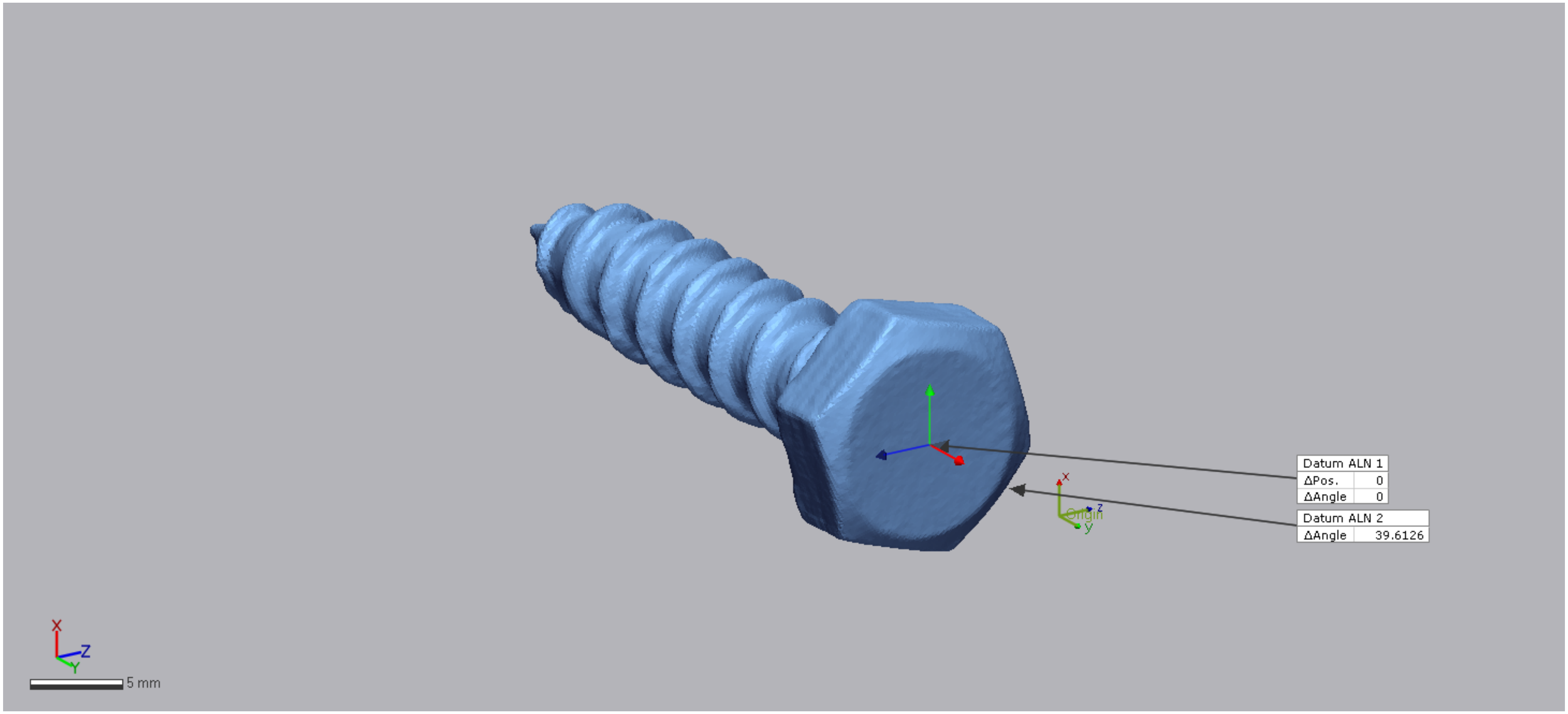
Product Name	[Product Name]		Department	[Department]		Date	Dec 18, 2017
Part Name	[Part Name]		Inspector	[Inspector]		Unit	mm

Result Data - 1 : View Part



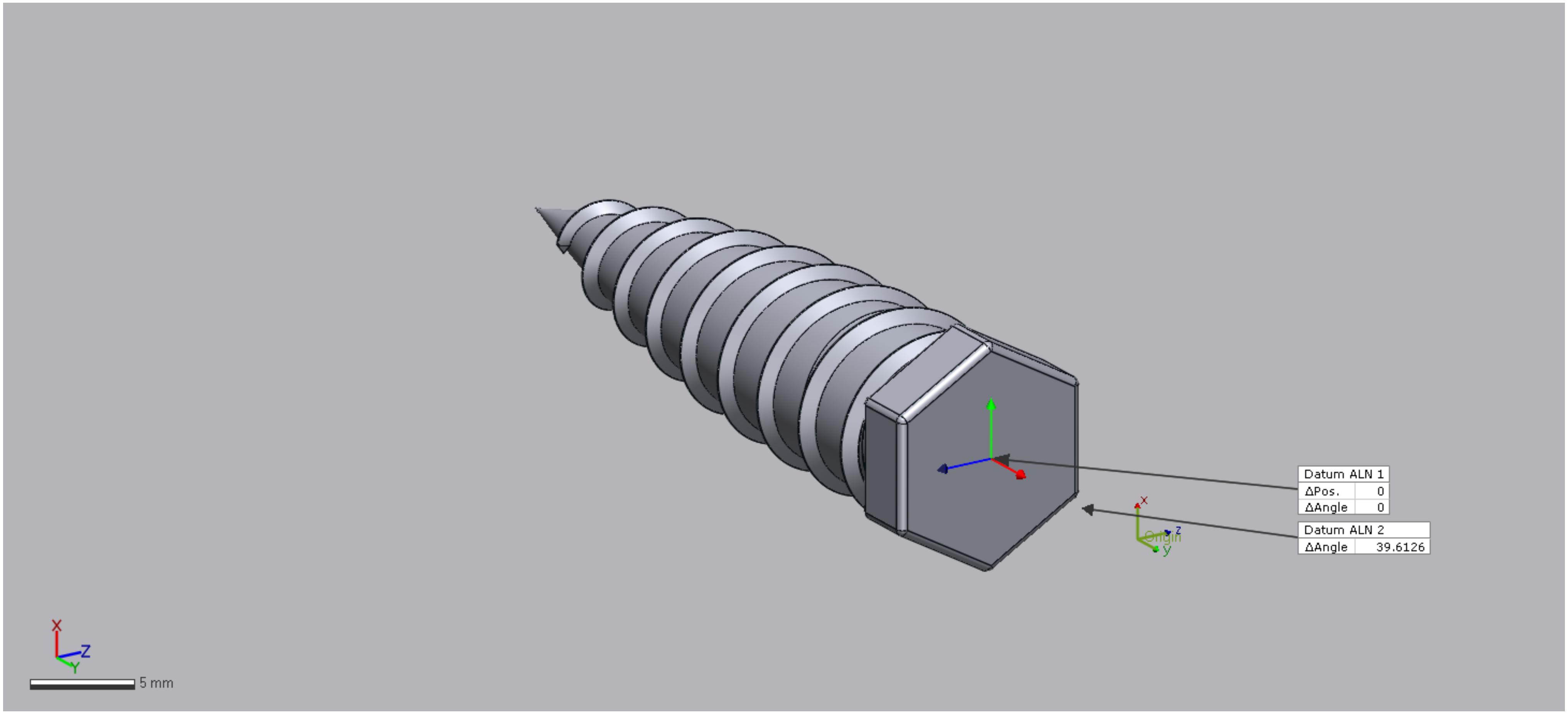
Product Name	[Product Name]	Department	[Department]	Date	Dec 18, 2017
Part Name	[Part Name]	Inspector	[Inspector]	Unit	mm

Result Data - 1 :   View Scanned Part



Product Name	[Product Name]	Department	[Department]	Date	Dec 18, 2017
Part Name	[Part Name]	Inspector	[Inspector]	Unit	mm

Result Data - 1 :   Scanned Aligned with CAD

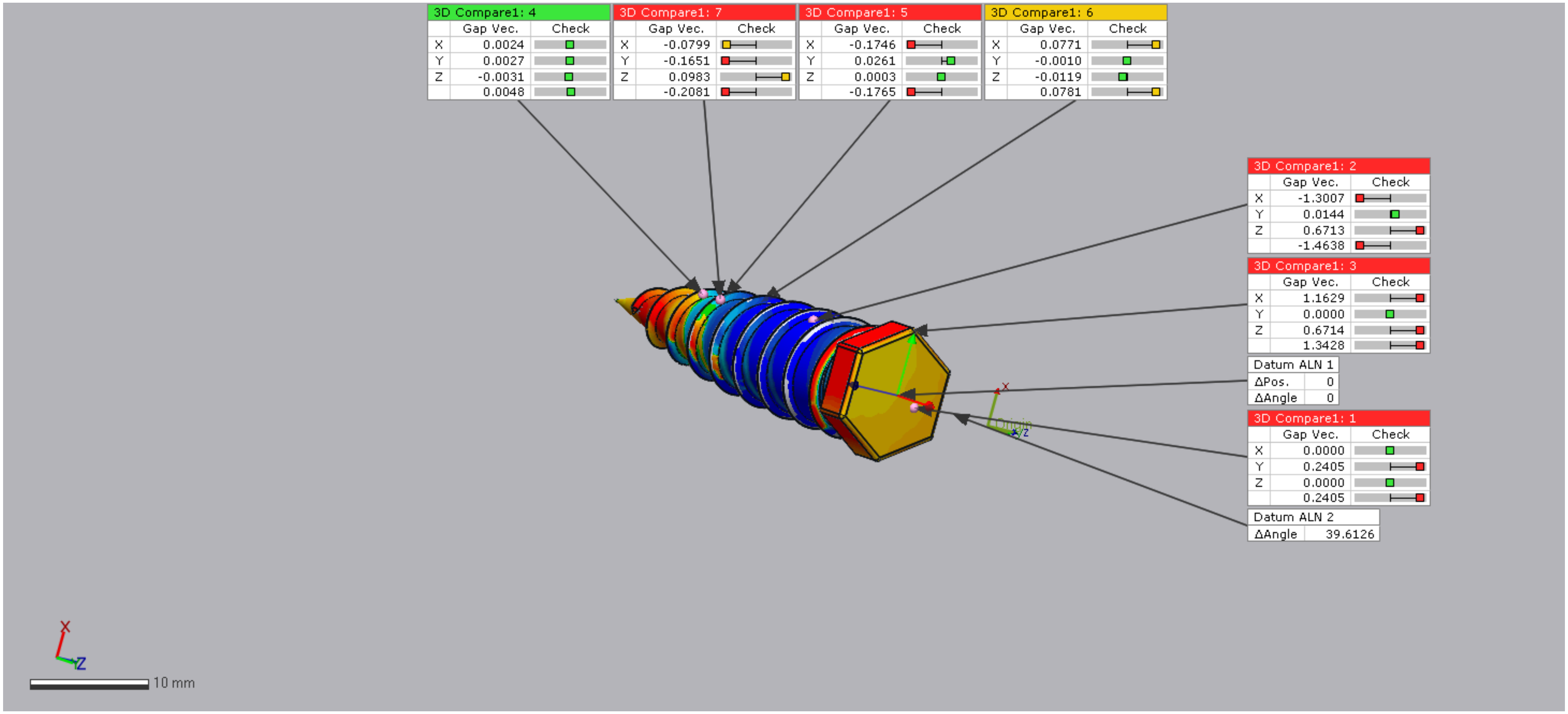


Product Name	[Product Name]
Part Name	[Part Name]

Department	[Department]
Inspector	[Inspector]

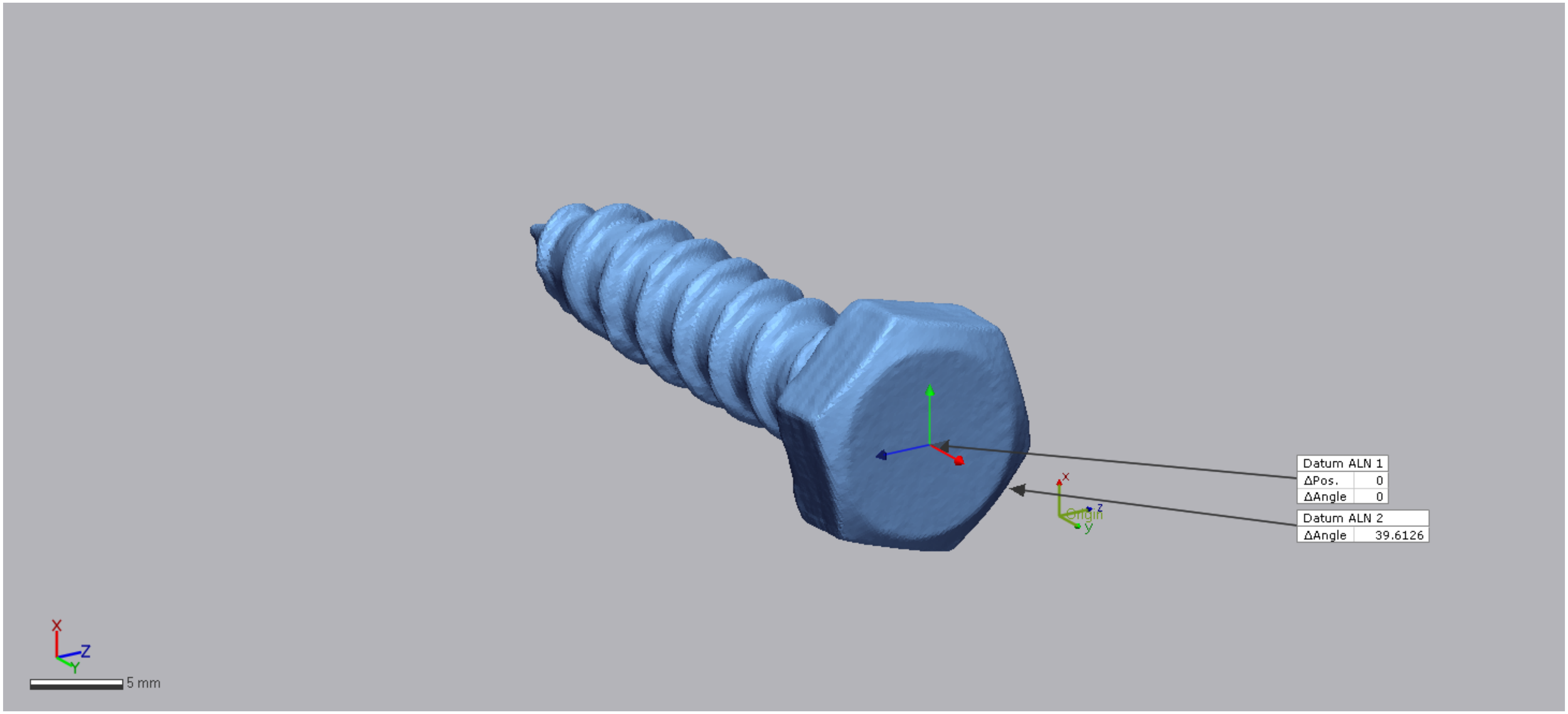
Date	Dec 18, 2017
Unit	mm

Result Data - 1 :　View 1



Product Name	[Product Name]	Department	[Department]	Date	Dec 18, 2017
Part Name	[Part Name]	Inspector	[Inspector]	Unit	mm

Result Data - 1 : View 2

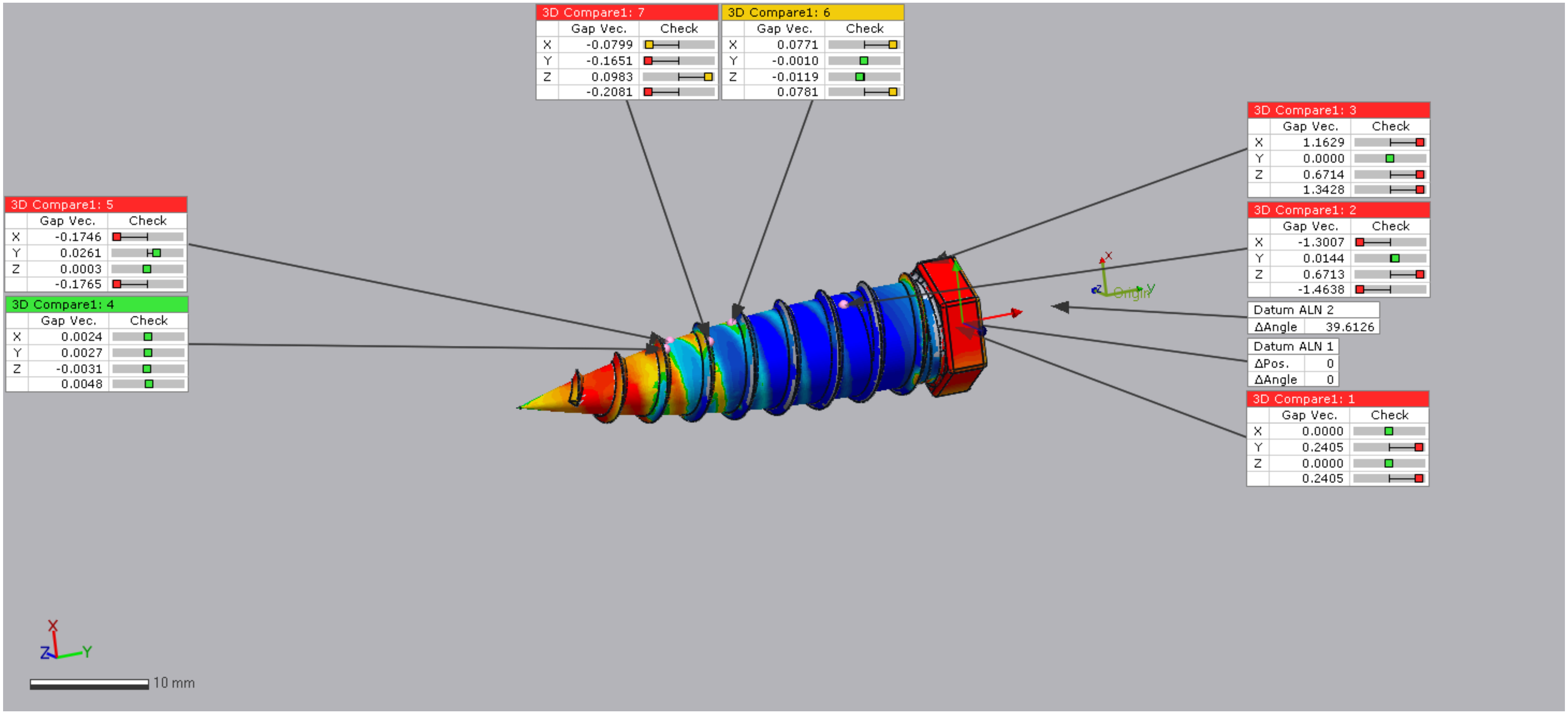


Product Name	[Product Name]
Part Name	[Part Name]

Department	[Department]
Inspector	[Inspector]

Date	Dec 18, 2017
Unit	mm

Result Data - 1 :   Compare Data

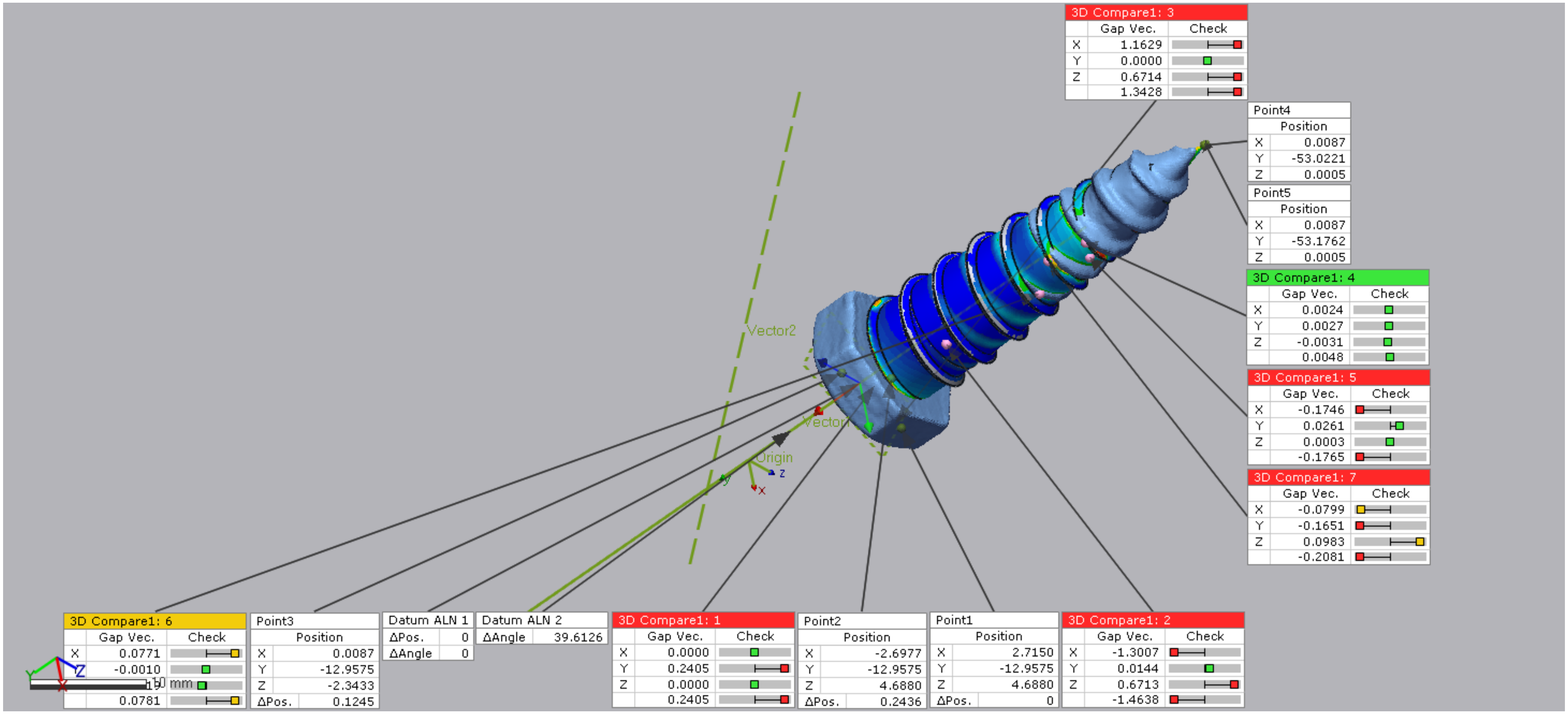


Product Name	[Product Name]
Part Name	[Part Name]

Department	[Department]
Inspector	[Inspector]

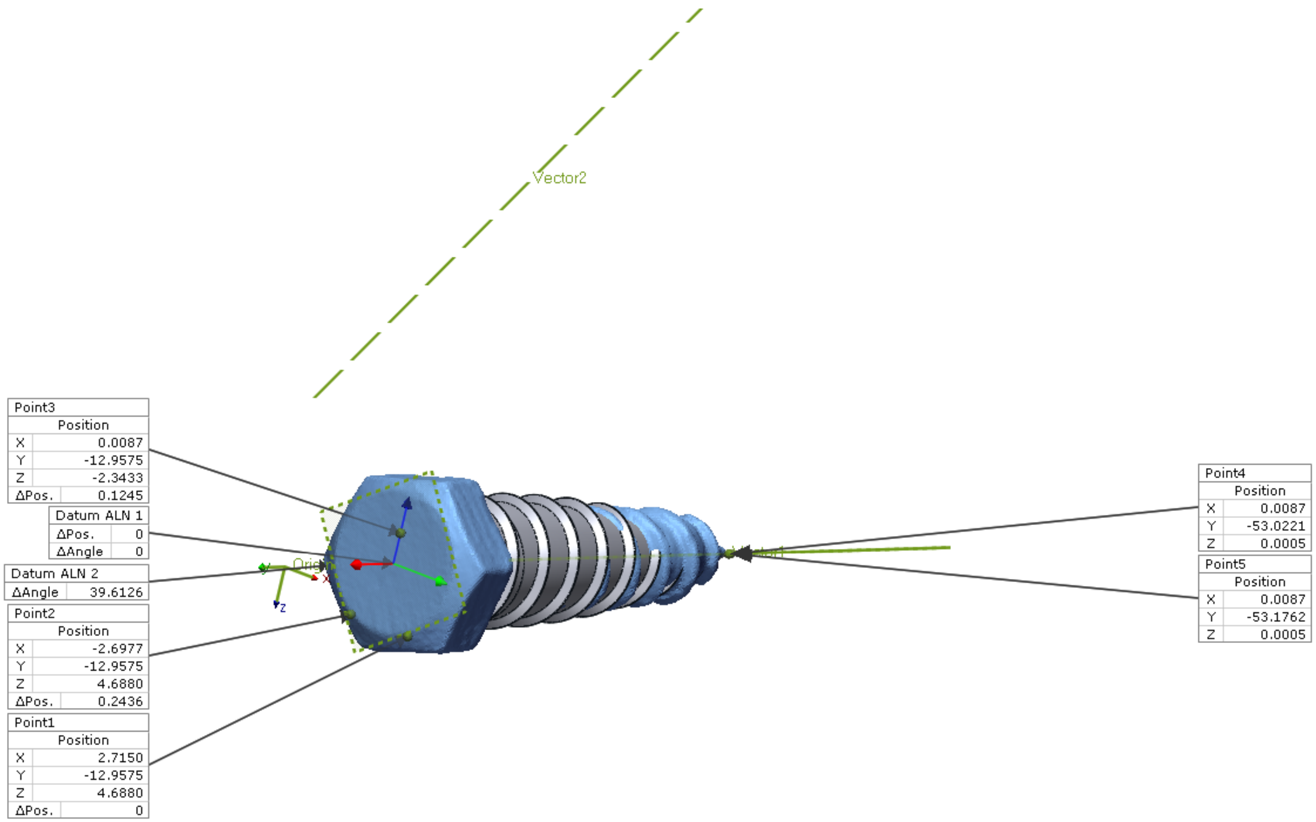
Date	Dec 18, 2017
Unit	mm

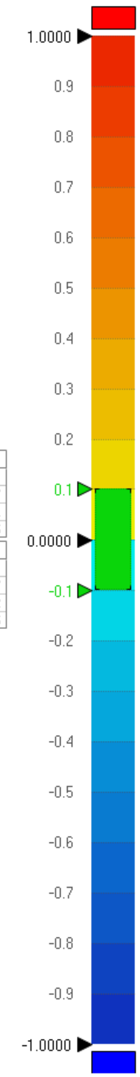
Result Data - 1 :   Compare Data 2

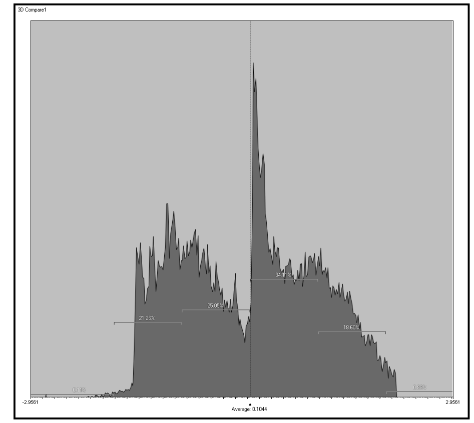


Product Name	[Product Name]	Department	[Department]	Date	Dec 18, 2017
Part Name	[Part Name]	Inspector	[Inspector]	Unit	mm

Result Data - 1 : 3D Compare1







Min.	-2.1409
Max.	2.1489
Avg.	0.1044
RMS	0.9563
Std. Dev.	0.9506
Var.	0.9036
+Avg.	0.8395
-Avg.	-0.8008
In Tol.(%)	3.6287
Out Tol.(%)	96.3713
Over Tol.(%)	53.6547
Under Tol.(%)	42.7166

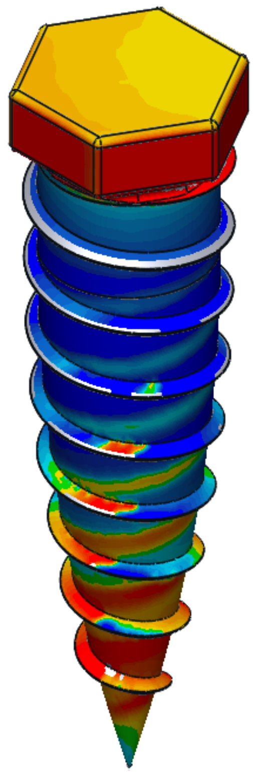
Product Name	[Product Name]	Department	[Department]	Date	Dec 18, 2017
Part Name	[Part Name]	Inspector	[Inspector]	Unit	mm

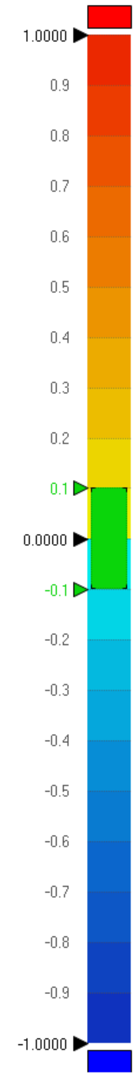
Name	Min.	Max.	Avg.	RMS	Std. Dev.	Var.	+Avg.	-Avg.
3D Compare1	-2.1409	2.1489	0.1044	0.9563	0.9506	0.9036	0.8395	-0.8008

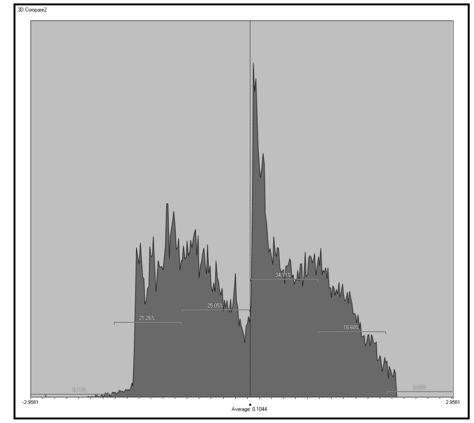
Name	Result Name	Tolerance	Gap Dist.	Reference Pos.			Measured Pos.		
				X	Y	Z	X	Y	Z
3D Compare1:	Result Data - 1	±0.1	0.2405	-0.686	-12.9575	2.0616	-0.686	-12.717	2.0616
3D Compare1:	Result Data - 1	±0.1	-1.4638	3.8105	-24	-2	2.5098	-23.9856	-1.3287
3D Compare1:	Result Data - 1	±0.1	1.3428	5.2773	-15	1	6.4402	-15	1.6714
3D Compare1:	Result Data - 1	±0.1	0.0048	2.8796	-40	-1.5	2.8821	-39.9973	-1.5031
3D Compare1:	Result Data - 1	±0.1	-0.1765	3.1108	-39	0	2.9362	-38.9739	0.0003
3D Compare1:	Result Data - 1	±0.1	0.0781	3.7585	-33.5	-0.5	3.8356	-33.501	-0.5119
3D Compare1:	Result Data - 1	±0.1	-0.2081	2.9859	-36.4	-2.4	2.906	-36.5651	-2.3017

Product Name	[Product Name]	Department	[Department]	Date	Dec 18, 2017
Part Name	[Part Name]	Inspector	[Inspector]	Unit	mm

Result Data - 1 : 3D Compare2







Min.	-2.1409
Max.	2.1489
Avg.	0.1044
RMS	0.9563
Std. Dev.	0.9506
Var.	0.9036
+Avg.	0.8395
-Avg.	-0.8008
In Tol.(%)	3.6287
Out Tol.(%)	96.3713
Over Tol.(%)	53.6547
Under Tol.(%)	42.7166

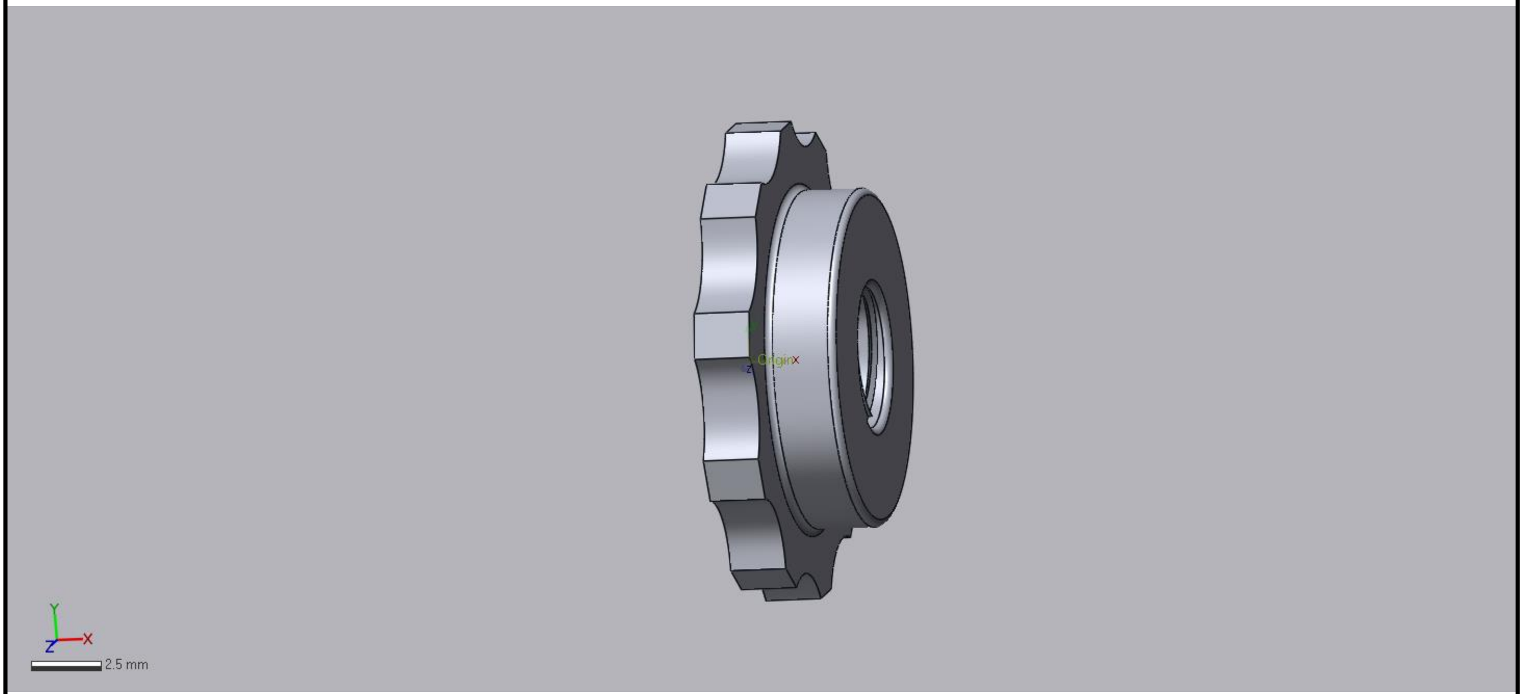
Product Name	[Product Name]	Department	[Department]	Date	Dec 18, 2017
Part Name	[Part Name]	Inspector	[Inspector]	Unit	mm

Name	Min.	Max.	Avg.	RMS	Std. Dev.	Var.	+Avg.	-Avg.
3D Compare2	-2.1409	2.1489	0.1044	0.9563	0.9506	0.9036	0.8395	-0.8008

Product Name	[Product Name]		Department	[Department]		Date	Dec 18, 2017
Part Name	[Part Name]		Inspector	[Inspector]		Unit	mm

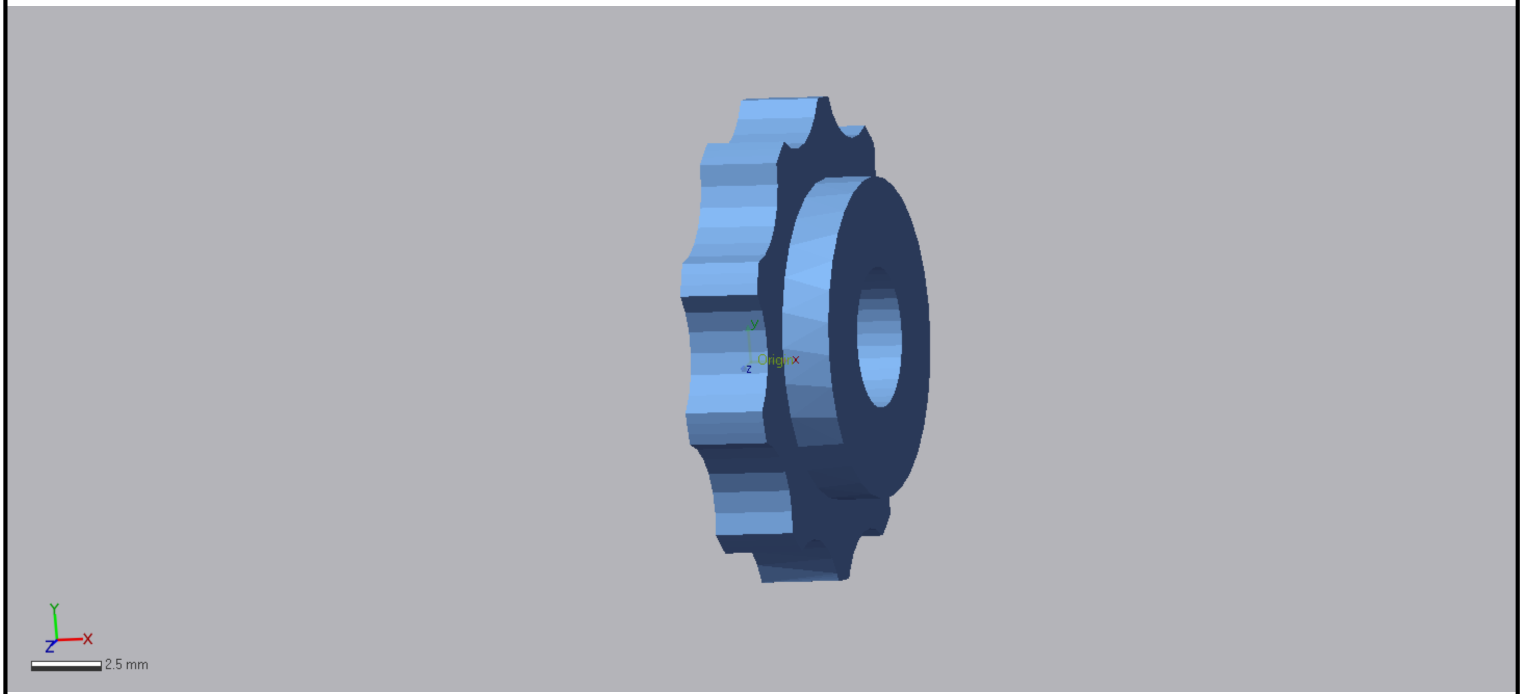
Product Name	Custom Nut
Part Name	N/A
Part Number	10
Department	Mechanical Engineering
Inspector	Ismael, Udit, Yash
Date	Dec 19, 2017
Unit	mm

Result Data - 1 : Model



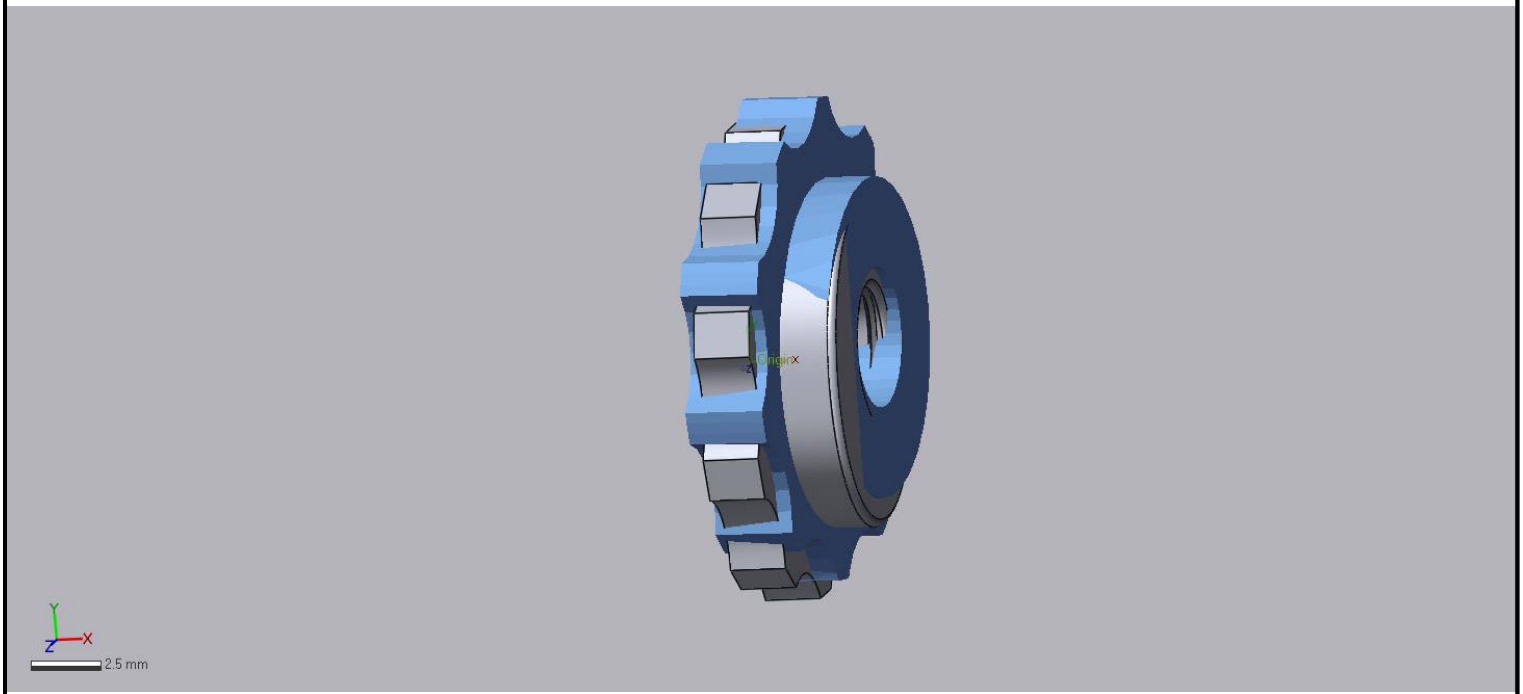
Product Name	Custom Nut	Department	Mechanical Engineering	Date	Dec 19, 2017
Part Name	N/A	Inspector	Ismael, Udit, Yash	Unit	mm

Result Data - 1 : Scanned Model



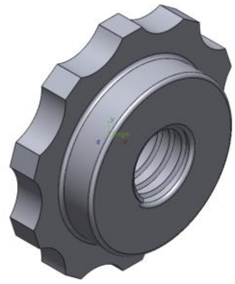
Product Name	Custom Nut	Department	Mechanical Engineering	Date	Dec 19, 2017
Part Name	N/A	Inspector	Ismael, Udit, Yash	Unit	mm

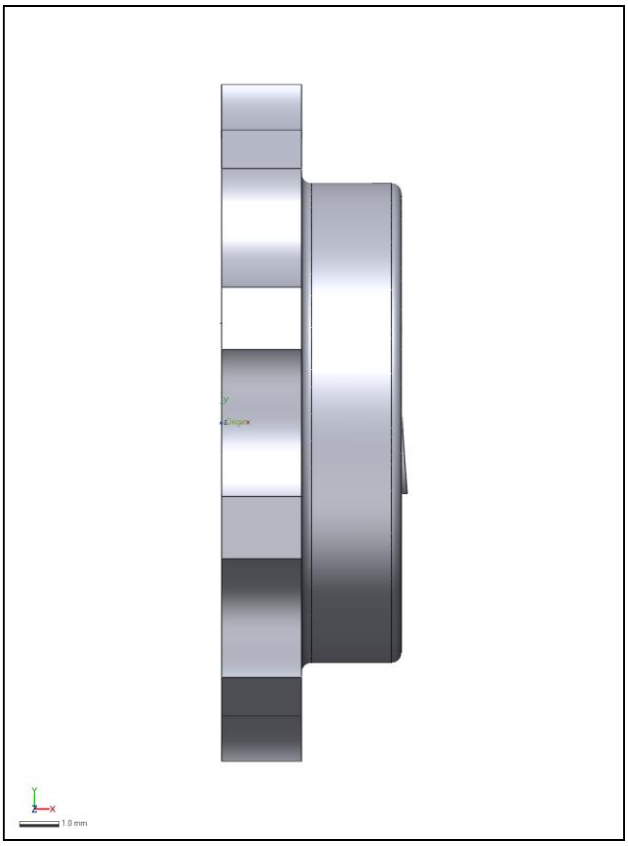
Result Data - 1 : Aligned Model

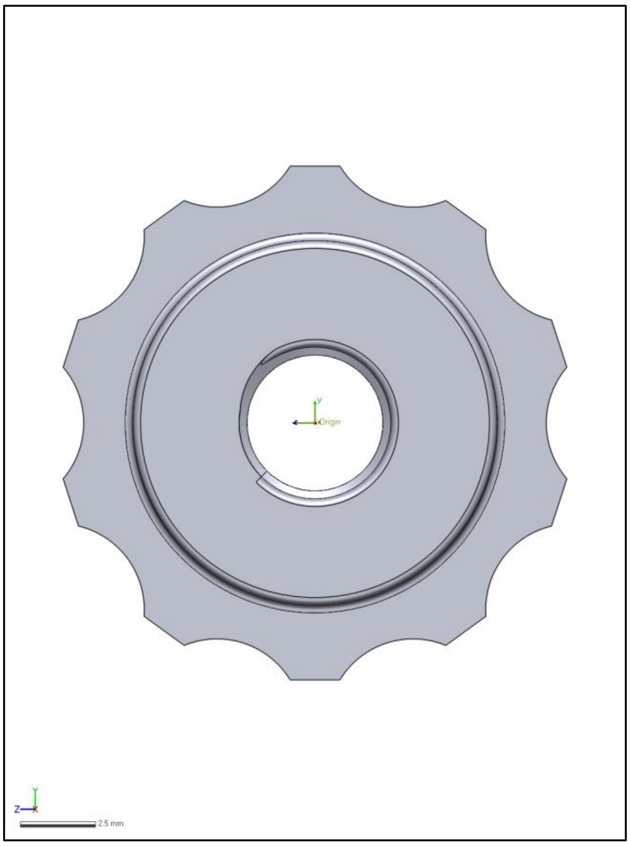


Product Name	Custom Nut	Department	Mechanical Engineering	Date	Dec 19, 2017
Part Name	N/A	Inspector	Ismael, Udit, Yash	Unit	mm

Result Data - 1 : Reference Data - Nut

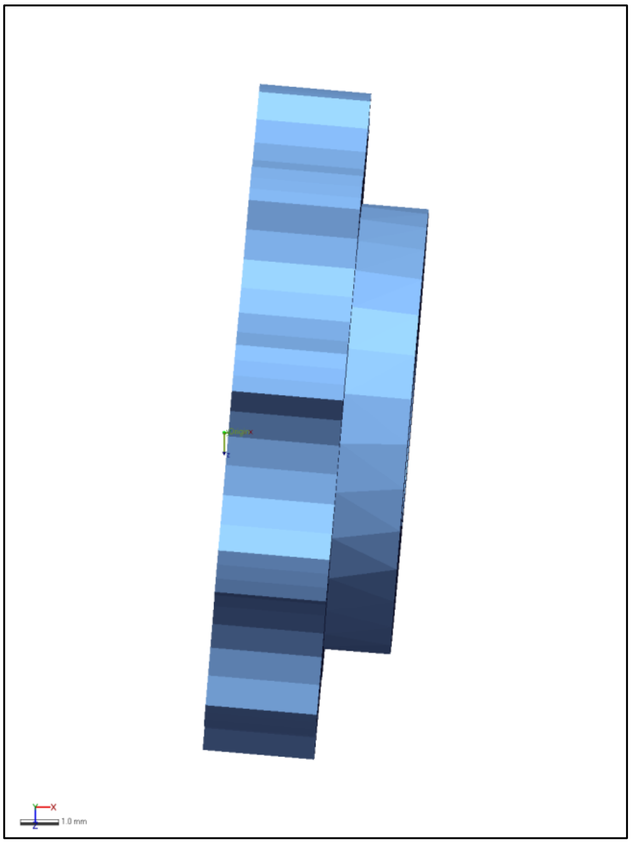


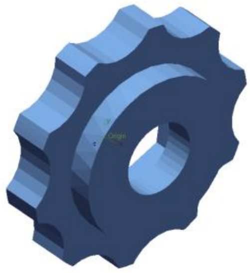


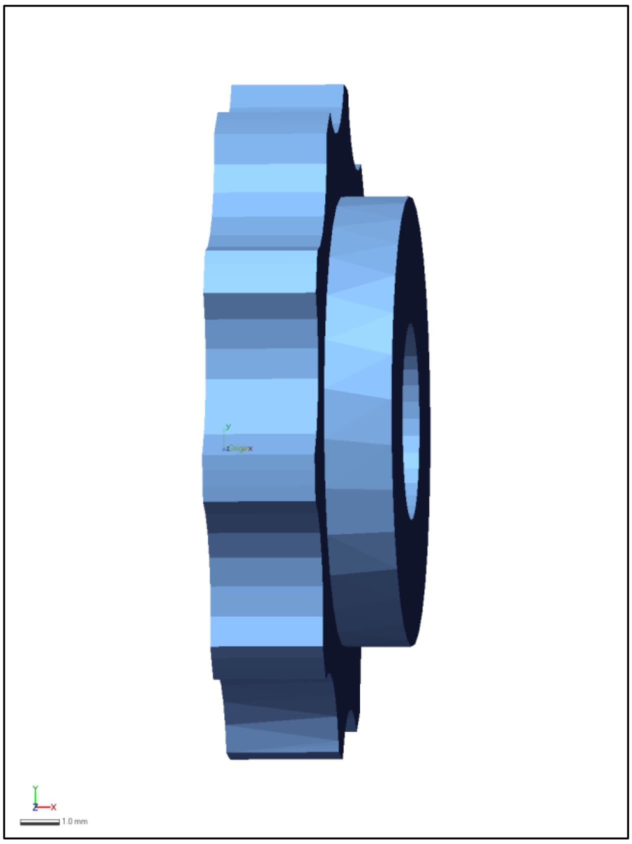


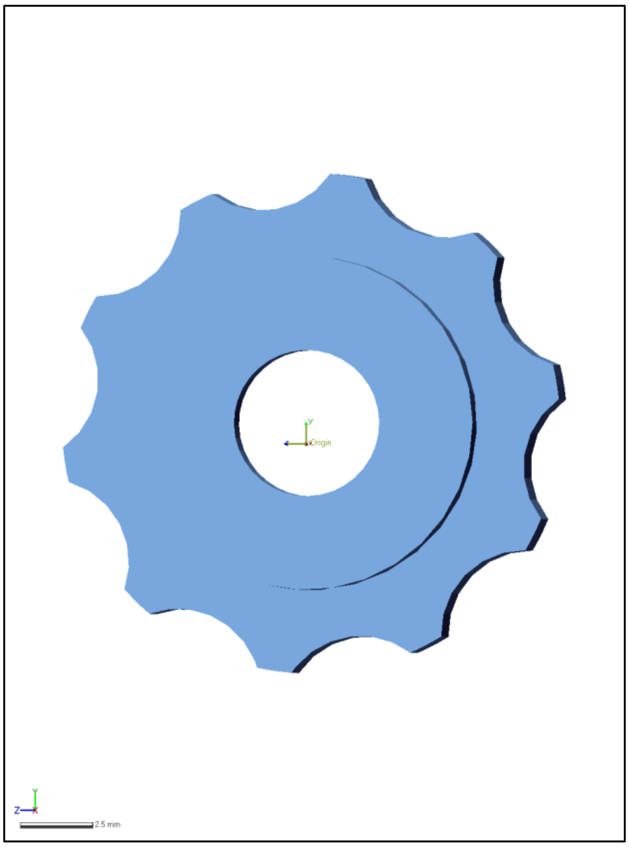
Product Name	Custom Nut	Department	Mechanical Engineering	Date	Dec 19, 2017
Part Name	N/A	Inspector	Ismael, Udit, Yash	Unit	mm

Result Data - 1 : Measured Data - M5Knob







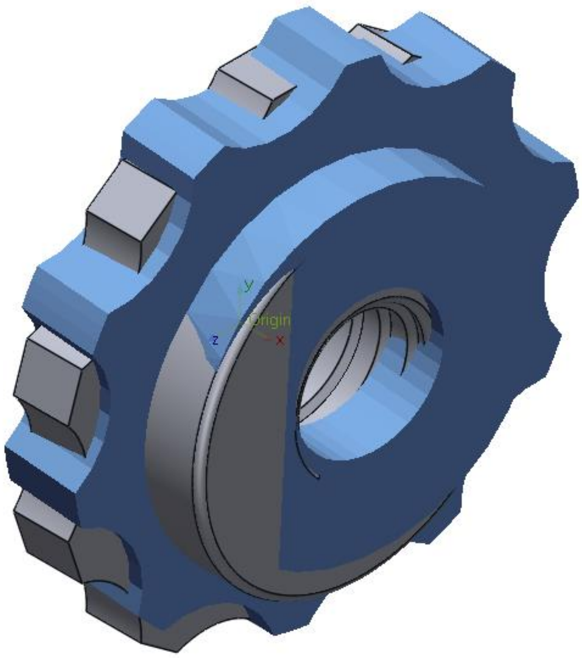


Product Name	Custom Nut	Department	Mechanical Engineering	Date	Dec 19, 2017
Part Name	N/A	Inspector	Ismael, Udit, Yash	Unit	mm

Result Data - 1 : Transform1

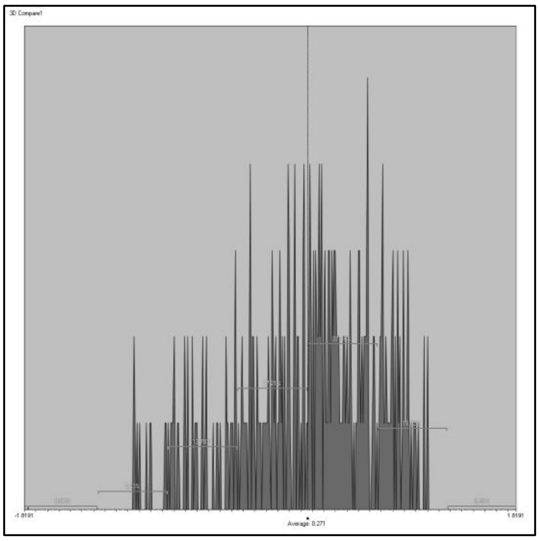
Matrix

0.0076	-0.0859	0.9963	0.8278
0.9892	0.1468	0.0052	-9.0082
-0.1467	0.9854	0.0861	-7.3463
0	0	0	1

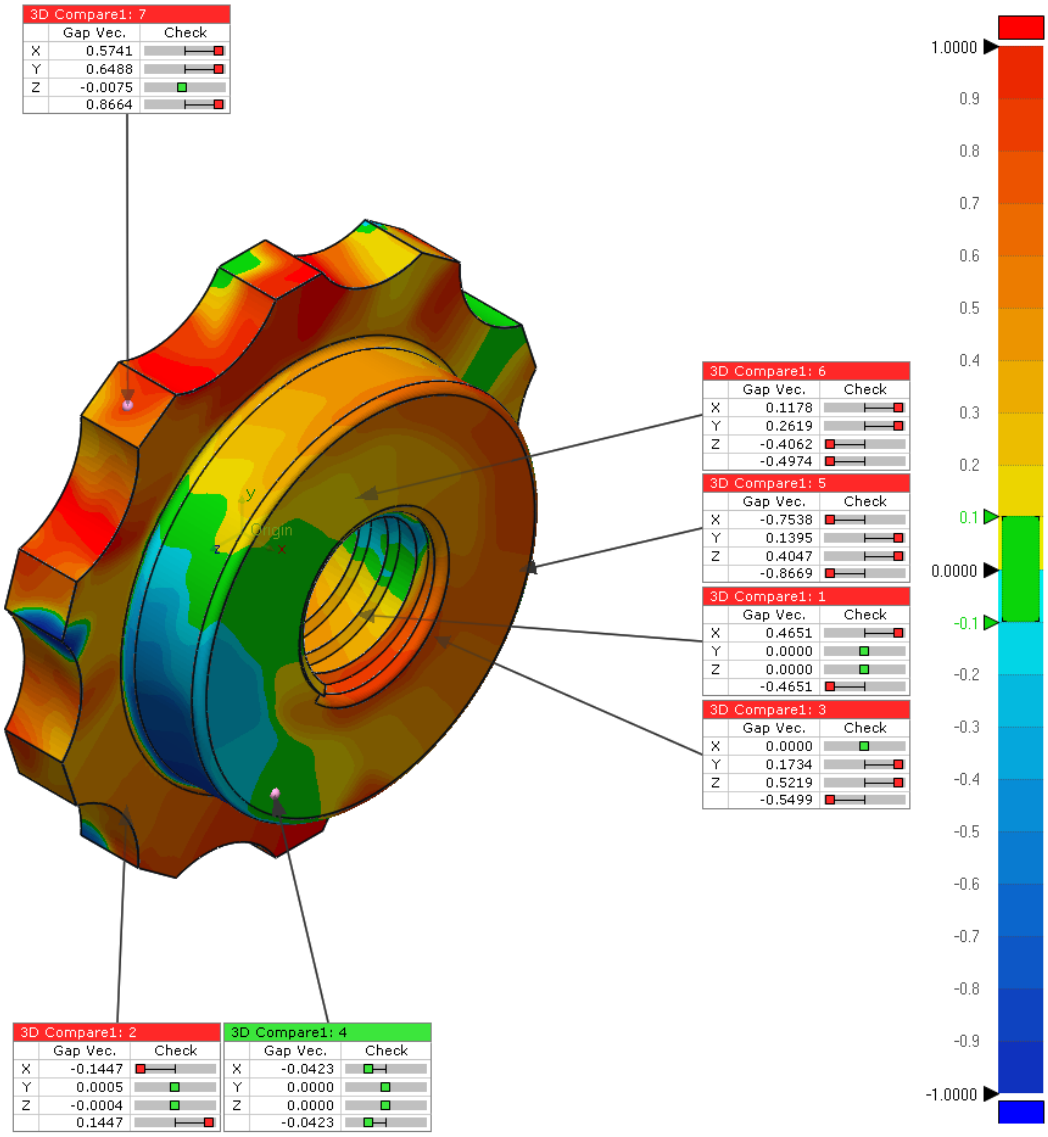


Product Name	Custom Nut	Department	Mechanical Engineering	Date	Dec 19, 2017
Part Name	N/A	Inspector	Ismael, Udit, Yash	Unit	mm

Result Data - 1 : 3D Compare1



Min.	-1.0072
Max.	1.1674
Avg.	0.271
RMS	0.5829
Std. Dev.	0.516
Var.	0.2663
+Avg.	0.5319
-Avg.	-0.4029
In Tol.(%)	10.2473
Out Tol.(%)	89.7527
Over Tol.(%)	66.0777
Under Tol.(%)	23.6749



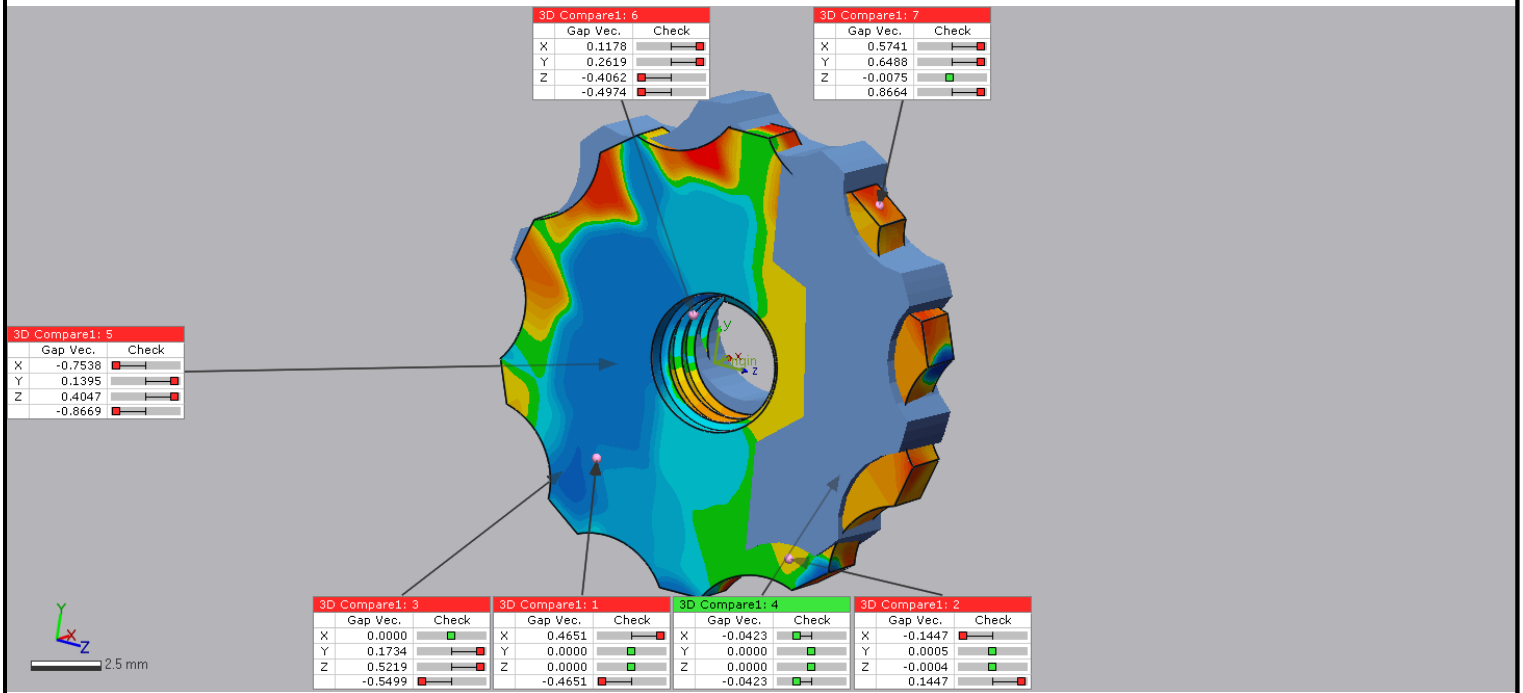
Product Name	Custom Nut	Department	Mechanical Engineering	Date	Dec 19, 2017
Part Name	N/A	Inspector	Ismael, Udit, Yash	Unit	mm

Name	Min.	Max.	Avg.	RMS	Std. Dev.	Var.	+Avg.	-Avg.
3D Compare1	-1.0072	1.1674	0.271	0.5829	0.516	0.2663	0.5319	-0.4029

Name	Result Name	Tolerance	Gap Dist.	Reference Pos.			Measured Pos.		
				X	Y	Z	X	Y	Z
3D Compare1: 1	Result Data - 1	±0.1	-0.4651	0	-4.4806	-3.9899	0.4651	-4.4806	-3.9899
3D Compare1: 2	Result Data - 1	±0.1	0.1447	0	-6.232	4.0363	-0.1447	-6.2315	4.0359
3D Compare1: 3	Result Data - 1	±0.1	-0.5499	1	-5.5	-5.6991	1	-5.3266	-5.1772
3D Compare1: 4	Result Data - 1	±0.1	-0.0423	4.5	-3.9828	3.3724	4.4577	-3.9828	3.3724
3D Compare1: 5	Result Data - 1	±0.1	-0.8669	4	-2	-5.6569	3.2462	-1.8605	-5.2522
3D Compare1: 6	Result Data - 1	±0.1	-0.4974	1.9477	0.9946	-2.0087	2.0655	1.2564	-2.4148
3D Compare1: 7	Result Data - 1	±0.1	0.8664	1	6.8251	5	1.5741	7.4739	4.9925

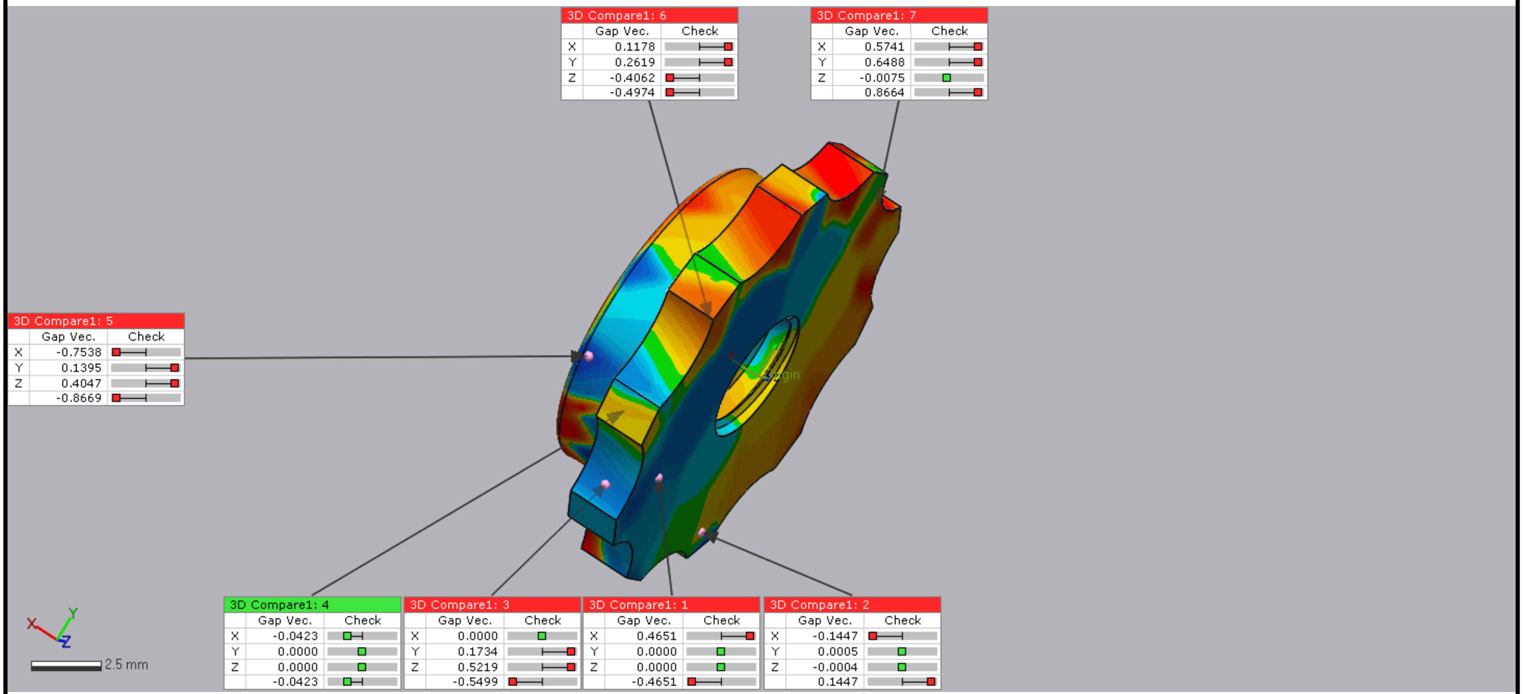
Product Name	Custom Nut	Department	Mechanical Engineering	Date	Dec 19, 2017
Part Name	N/A	Inspector	Ismael, Udit, Yash	Unit	mm

Result Data - 1 : 3D compare Data



Product Name	Custom Nut	Department	Mechanical Engineering	Date	Dec 19, 2017
Part Name	N/A	Inspector	Ismael, Udit, Yash	Unit	mm

Result Data - 1 : 3D compare Data v2



Product Name	Custom Nut	Department	Mechanical Engineering	Date	Dec 19, 2017
Part Name	N/A	Inspector	Ismael, Udit, Yash	Unit	mm

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