ENGINEERING-DESIGN RESEARCH PAPER

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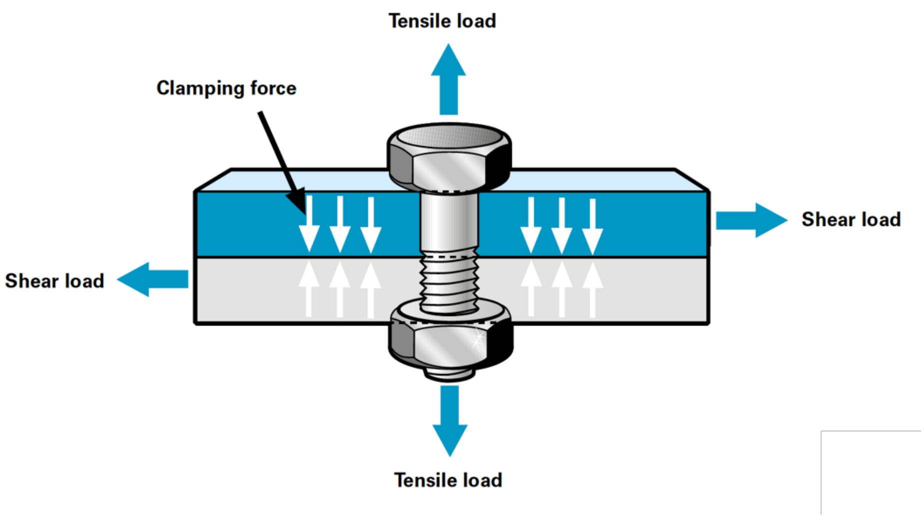
Engineering-Design Research Paper

How has the Aster® Bolt been the Next Big Step in the Evolution of the Aerospace Fastenings?

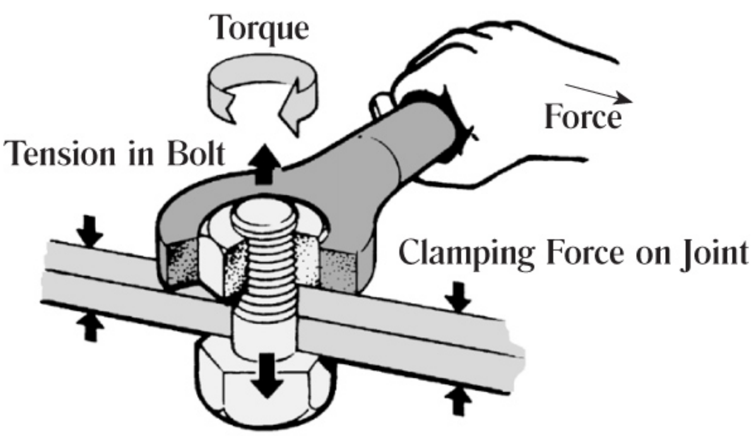
A fastening is a hardware device that mechanically joins or affixes two objects together. A link that can be removed or dismantled without the destruction or damage of the joining components can be termed as a non-permanent link. Welded links and riveted links can be termed as permanent links, which if required to be removed tends to damage or destruct both the joining components as well as the link itself. There is tremendous variety of fastenings, examples of which are: bolts, battens, buckles, buttons, clamps, clasps, cleco, clips, flanges, grommets, latches, nails, pegs, pins, rivets, anchors, staples, stitches and zippers. The basis of a fastening is basically a screw thread. - The male part is basically the screw with an external thread and the female part is a hole with an internal thread. The female part can also be a nut. When choosing a fastening for industrial applications, it is important to consider a variety of factors. The threading, the applied load on the fastening, the stiffness of the fastening, and the number of fastenings needed are taken into account. Traditionally the largest consumers of the fastening manufacturing industry are the automotive and aerospace industries who, in just the United States alone, specifically buy tens of billions of metallic fastenings a year.

Metallic Fastenings are most commonly produced from Carbon Steel, Alloy Steel, Stainless Steel, Inconel Stainless Steel, Titanium, Aluminum and various Alloys. In many cases, special coatings or plating may be applied to metal fastenings to improve their performance characteristics by, for example, enhancing corrosion resistance. Common coatings/plating includes zinc, chrome, and hot dip galvanizing but in the field of aeronautics, cadmium is the industrial standard.

In aviation, the most commonly used metallic fastening is the bolt. A bolt is a form of threaded fastening with an external male thread. Bolts are for the assembly of two unthreaded components, with the aid of a nut. Bolts are often used to make a bolted link. This is a combination of the nut applying an axial clamping force and also the shank of the bolt acting as a dowel, pinning the link against sideways shear forces. For this reason, many bolts have a plain unthreaded shank (called the grip length) as this makes for a better, stronger dowel. The presence of the unthreaded shank has often been given as characteristic of bolts vs. screws, but this is incidental to its use, rather than defining. The grip length should be chosen carefully, to be around the same length as the thickness of the materials, and any washers, bolted together. Too short places the dowel shear load onto the threads, which may cause fretting wear on the hole. Too long prevents the nut from being tightened down correctly. No more than two turns of the thread should be within the hole.



Bolts work solely as a result of two physical phenomenon, torque and tension. Torque is a twisting or turning force that tends to cause rotation around an axis, which might be a center of mass or a fixed point. Torque can also be thought of as the ability of something that is rotating, such as a gear or a shaft, to overcome turning resistance. It is measured in pounds per foot or newton per meter. In the case of fastenings, it has its own use, torque is the amount of energy it takes to spin the nut up along the threads of a bolt. On the other hand, tension is a force along the length of a medium, especially a force carried by a flexible medium, such as a rope or cable. In much the same way, for fastenings, tension is the stretch or elongation in a bolt that provides the clamping force in a link. So, in a nutshell, as the nut and bolt are tightened, two objects are clamped together. The thread angle in the bolt converts the force applied into tension (or stretch) in the bolt shank. The amount of the tension created in the bolt is critical. A bolt tensioned properly works at its optimum efficiency and will resist coming undone. However, if the tension is too low, the nut could vibrate or work loose. If the tension is too high (overstretched), the bolt could break. Every bolt has a correct optimum torque/tension figure for each fastening application. It is important to have these figures available so that the end product will be safe, efficient and economical.



The importance of torque in many applications cannot be overemphasized. Under torque can result in the unnecessary wear of nuts and fastenings as well as the parts they join together. When insufficient pressures are applied uneven loads would be transported throughout the assembly which may result in excessive wear or premature failure due to fatigue. Over-torqueing can be equally as damaging because failure of a nut or bolt from overstressing the fastening and secured areas.

A manufactured product's quality and integrity are completely dependent upon the reliability of fastenings and the elastic interaction between the mating components. The objective is to clamp parts together with a tension greater than any external force trying to separate them. The part then remains under constant stress and is immune to fatigue.

The precise control of torque is a key to a quality assembly and can ensure that products perform as expected. In many cases, before finished products even reach the market, companies have spent a great deal of time and money for disposal or repair of damaged parts, during assembly, which are the results of improper application of torque. Even worse, if these products (albeit unintentionally) make it to market, manufacturers are faced with customer dissatisfaction when products fall apart due to loose screws or stripped threads.

Manufacturing costs may also be reduced through precise torque control. Any organization would save costs once they realized that unless and until they practice precise torque control any product they create would create would have the fastenings collapse prematurely, cutting into their profits.

Product safety and related liability exposure for manufactures can also be dependent on the proper utilization of threaded fastenings. In critical applications where safety is an issue, the proper use of fastenings can decrease the incidence of expensive lawsuits and product recalls.

Reducing worker fatigue also has to be considered in achieving production line consistency and reducing the lost time costs associated with repetitive use injuries. When fatigue occurs due to high repetition or strenuous effort, torque control tools are available which improve ergonomics and reduce the effort for consistent torque application. When planning a production area, it pays dividends in the long term to plan the ergonomics of the operation and consult a health and safety inspector or ergonomic manager. Ensure both the workplace and the assembly operations are compatible with the majority of operators who will work there. This can reduce future costs arising from work-related health disorders among operators, along with costs arising from poor product quality. Also, the need to redesign the production system later may be avoided.

Wide varieties of tools are available to control and measure the amount of torque applied to fastenings. These “torque control tools” utilize calibrated torque setting mechanisms that may be factory pre-set, or user-definable. When the specified torque setting is reached, the tool provides a visual, audible, or tactile signal.

For low production applications, or to verify torque out in the field, manual torque wrenches are available that may have dial indicators, emit an audible click, or slip when the specified torque value is achieved. Manual torque screwdrivers work on the same principle by providing a slipping sensation when the specified torque is reached. Electric or pneumatic screwdrivers can be incorporated into workstations to speed up production and reduce repetitive motion injuries and carpal tunnel syndrome.

For large fastenings in industrial applications, manual and powered torque multipliers are often used to replace impact wrenches. Torque multipliers are available that can deliver over 30,000 ft. pounds of torque, with precision.

Another variable to be considered is whether torque will be applied statically or dynamically. Static torque is applied by hand and occurs relatively slowly. Dynamic torque is applied with a power tool at a high rate of speed. More tension is normally generated by dynamic torque than static at a given torque setting, because of the momentum generated by the tool's motor and gear assembly (inertia) and the lower coefficient of friction.

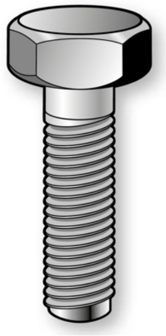
Varying loads and vibrations represent a special challenge for threaded fastenings. Since a properly torqued threaded fastening is always under steady tension in connecting two mated components, it is virtually immune to fatigue. However, if the initial bolt tension is to low, the bolt will vibrate loose or break and the link will quickly fail.

When arbitrating the right specific torque values, other variables are accounted for. One being the max load that could be placed upon the fastening, another being the rigidity of the material that is being joined and also whether the link is hard or soft. A hard link joins the materials together with direct contact. In such cases, the fastening may rotate very few degrees, upon coming in contact with the other material, in order to develop a full clamping force. A soft link, on the other hand, may contain a gasket. In such cases, to attain torque like that of the hard link, a fastening would have to go through many more degrees of rotation before it could generate a full clamping force.

If one would make use of a torque tool of quality, they would in a literal sense make a safer world through both precision and accuracy. In order for a company to ensure their products standards of quality, reliability and safety, torque control would be essential. Fastenings that are not sufficiently torqued could be prone to vibrations and come undone, and torque in excessive amounts can wear-down their threads. The failure of a miniscule fraction-of-a-dollar fastening that has not been effectively tightened could eventually cause severe failures, which would range at an exorbitantly high price point in damages.

To answer to the industry's call to one side access pin fastening systems, the Hex-recess bolt was created and set as the industry standard since the 1950s. It was a fastening system that functioned well, and multiple industries had grown accustomed to it (although there were significant drawbacks that we will address later). The fastener industry could not foresee any sort of change to this already working model, especially considering the cost it would involve taking the leap by both the consumers and manufacturers sides to set whatever new technology that would be created to be the industry's new standard. This led to no real need for innovation in the sector and the fastener industry's main goal was to ensure they were growing their profits through selling larger quantities rather than considering innovating both the quality and technology behind fasteners.

The Hex-bolt, as seen below, has a threaded system at one end, and an elongated unthreaded neck that runs all the way to head at the other end (it can be any type of head – Flat, Oval, Pan Truss, Round, Button, Socket, Protruding, 100, 130, Shear, Tension). At the tip of the threaded end lies a hexagonal recess that bores into the length of the bolt and is meant for its subsequently paired drill bit.



This bolt is not conventional in the sense that the recess (or whatever tool is being utilized to hold the bolt down as the nut is being fastened on the thread) usually happens to be placed on the head, opposite to the sides with the thread. Instead the recess is placed on the side of the threads creating a one-sided pin fastening system. This is extremely functional in the aerospace industry as there are multiple needs to implement the use of fasteners when only one side can be accessed, for example if the fuselage of an aircraft is to be smooth and aerodynamic on the outside, then the bolt would have to be held in from the inside and the nut would have to be screwed from the inside just as well.

Besides the recess, everything about the conventional Hex bolt is at its pinnacle in terms of - the material, the coating, the manufacturing process, etc. There is not much that the industry can advance in this field simply because the technology does not exist yet or that the need to fix something that is not broken is not great enough.

The Material –

There is a wide range of metals that aerospace fasteners can be made out of but the most common are Aluminum, Titanium and Inconel, which will be made more understandable later in this section. Here is a list of most metals and what their limitations are when it comes to making fastener.

- Low Carbon Steel - generally contains less than 0.25% of carbon. It has outstanding ductility and toughness, is easily machined and welded and it relatively inexpensive to produce. It has a tensile strength between 60000 psi to 80000 psi.
- Medium Carbon Steel - has carbon content of between 0.25% and 0.60%. It is easily heat treated and it has a tensile strength between 100000 psi to 120000 psi.
- Alloy Steel - is carbon steel that has additives like boron, manganese, chromium, silicon, etc. Additions of these elements aid the alloy in developing a higher capacity to be heat-treated, giving a wide rise to strength to ductility combinations. Alloy Steels have a tensile strength in excess of 150000 psi.
- Austenitic Stainless-Steel Alloys - is an Alloy Steel with Chromium content between 15% and 20% and Nickel content between 5% and 19%. The presence of Chromium creates an invisible surface film (Chromium Oxide) that resists oxidation and makes the metal "passive" or corrosion resistant. If the surface layer is damaged, it rebuilds itself (self-repairs) in the presence of oxygen. Thus, a Stainless-Steel Alloy's Achilles Heel would be a low-Oxygen or and Oxygen-free environment where the material would be susceptible to aggressive influences in the case that the surface layer gets damaged. This Stainless-Steel Alloy offers the higher degree of corrosion resistance than the other two. The tensile strength of Austenitic Stainless-Steel Alloys varies between 72000 psi and 115000 psi.
- Martensitic Stainless-Steel Alloys – contain between 12% and 18% Chromium, can be hardened by heat treatment, have poor welding characteristics and are considered

magnetic. Martensitic Stainless-Steel Alloys have a tensile strength that varies between 72000 psi and 160000 psi. This type of Stainless Steel should be only used in mildly corrosive environments

- Ferritic Stainless-Steel Alloys - contain between 15% and 18% Chromium and are non-heat treatable, magnetic and have very poor weld characteristics. The tensile strength of Ferritic Stainless-Steel Alloys is between 65000 psi to 87000 psi. It should not be used in environments of high corrosive elements.
- Nickel / Copper Alloys (Monel® 400, Monel K 500) - have excellent strength properties, exceptional toughness and ductility and perform well in both hot and cold extreme temperature environments. Fasteners made from Nickel-Copper Alloys have a tensile strength of 80000 psi whereas fasteners made from Nickel-Copper-Aluminum Alloys have a tensile strength of 130000 psi. Nickel and High-Nickel Alloy fasteners offer excellent performance and oxidation resistance at high temperatures, but their use is restricted by their high costs.
- Super Alloys (Hastelloy®, Inconel®, Incoloy®, Waspaloy®, Alloy 20, etc.) - are oxidation- and corrosion-resistant materials well suited for service in extreme environments subjected to high pressure and kinetic energy. When heated, the forms a thick and stable passivating oxide layer protecting the surface from further attacks. They retain strength over a wide temperature range, attractive for high-temperature applications where Aluminum and Steel would succumb to creep as a result of thermally induced crystal vacancies. Super Alloys' high temperature strength is developed by solid solution strengthening or precipitation strengthening, depending on the alloy.

- Aluminum – is a lightweight metal that has a high strength to weight ratio, good resistance to corrosion in more environments, excellent electrical and thermal conductivity, it is easily cold formed, or heat forged and easily machined. This is why Aluminum is the most popular choice for fasteners amongst those that are non-ferrous. The tensile strength for Aluminum is 13000 psi with pure Aluminum having a strength of 60000 psi.
- Titanium - as compared to Aluminum has superior strength to weight ratios, excellent utilized widely in the aerospace industry. Expanding upon the point made earlier about corrosion resistance, Titanium is highly corrosion resistant to chemical agents and aggressive oxidizing substances used in the chemical industry. Fasteners made of titanium have a tensile strength in excess of 150000 psi.
- When picking the material used in a fastener, the manufacturer has to consider, the tensile strength that the fastener should have, the accessibility of the material, the temperature it would be exposed to, the water exposure, the corrosive elements exposure, its reusability, the weight restrictions, the installation processes, the materials that the fastener would join, and lastly the aesthetics. As mentioned earlier, the strength to weight ratios, resistivity to corrosion and tensile strength makes Super Alloys, Titanium and Aluminum the industry standards when it comes to Aerospace Fasteners.

The Coating –

Much like the materials used in a fastener, there is an expansive range of coatings used to protect the fastener from corrosion. Corrosion is the deterioration and loss of a material and its critical properties due to chemical, electrochemical and other reactions of the exposed material surface with the surrounding environment. In the Aerospace Fastener Industry, there is a specific type of corrosion that a fastener is supposed to be able to withstand both within the system of the aircraft and in its immediate environment - Galvanic Corrosion.

Galvanic corrosion occurs when two different metals have physical or electrical contact with each other and are immersed in a common electrolyte, or when the same metal is exposed to electrolyte with different concentrations. In any given environment (one standard medium is aerated, room-temperature seawater), one metal will be either more *noble* or more *active* than others, based on how strongly its ions are bound to the surface. Two metals in electrical contact share the same electrons, so that the "tug-of-war" at each surface is analogous to competition for free electrons between the two materials. Using the electrolyte as a host for the flow of ions in the same direction, the noble metal will take electrons from the active one. In a galvanic couple, the more active metal (the anode) corrodes at an accelerated rate and the more noble metal (the cathode) corrodes at a slower rate. When immersed separately, each metal corrodes at its own rate.

Factors such as relative size of anode, types of metal, and operating conditions (temperature, humidity, salinity, etc.) affect galvanic corrosion. The surface area ratio of the anode and cathode directly affects the corrosion rates of the materials. Galvanic corrosion is often prevented by the use of sacrificial anodes.

In the case of the Aerospace industry, Galvanic corrosion occurred in two main situations. The first being in the case of metal-based aircraft bodies, with the body of the plane itself, and second, directly with the air. In both aspects water served as the medium whether it be rain, snow or humidity. In order to combat this form of corrosion, the fastener was coated in a durable and non-electrolytic coating so as to prevent the flow of electrons.

Of the many coatings that could be used for metals that are continuously exposed to outdoor weather for long durations of the time, the most common have been mentioned below.

- Zinc (Electroplated) – Ideally used to coat Steel. It has a very good degree of corrosion resistance.
- Zinc (Hot Dip Galvanizing) – Ideally used to coat Steel. Provides the maximum level of corrosion resistance.
- Zinc (Mechanically Deposited) – Ideally used to coat Steel. It has a very good degree of corrosion resistance depended upon the thickness of the coating.
- Anodizing – Ideally used to coat Aluminum. It provides an excellent degree of corrosion resistance. Obtained through Acid Electrolytic treatment. Hard oxide surface gives excellent protection.
- Black Chromate – Ideally used to coat Zinc and Cadmium Plated Parts, providing added protection to them. Obtained through chemical dip.
- Cadmium (Electroplated) – Ideally used to coat Steel. Excellent resistivity to corrosion. Losing popularity to Cadmium toxicity.
- Chromate (Clear) – Ideally used to coat Zinc and Cadmium Plated Parts. Very good to excellent protection from corrosion. Clear bright or iridescent chemical conversion coating applied to plated parts to enhance corrosion protection, coloring, and paint bonding.

- Chromate (Colored) – Ideally used to coat Zinc and Cadmium Plated Parts. Ideally used to coat Zinc and Cadmium Plated Parts. Very good to excellent protection from corrosion. Clear bright or iridescent chemical conversion coating applied to plated parts to enhance corrosion protection, coloring, and paint bonding.
- Chromium (Electroplated) – Can be used to coat most metals. Has relatively hard surface. Used for decorative purposes or to add wear resistance.
- Dichromate – Ideally used to coat Zinc and Cadmium Plated Parts. Very good to excellent protection from corrosion.
- Lacquering (Clear or Color Matched) – Can be used to coat all metals. Improves corrosion resistance depends on layer thickness. Clear or colored to match mating color or luster.
- Passivating – Ideally used to coat Stainless Steel. Excellent resistivity to corrosion. Chemical treatment. Removes iron particles and produces a passive surface so as to prevent rust.
- Phosphate (Color Coating) – Ideally used to coat Steel. Superior resistivity to corrosion. Chemically produced color coating. Available in blue, green, red, purple, etc.
- Zinc Phosphate/Manganese Phosphate – Ideally used to coat Steel. Good resistivity to corrosion. Black in color. Added protection when oiled. Good lubricity.
- Silver – Can be used to coat all metals. Excellent resistivity to corrosion. Decorative, expensive, excellent electrical conductor.

- Hot-Dip Aluminum – Ideally used to coat Steel. It has a very good degree of corrosion resistance. For maximum corrosion protection. Corrosion resistance is directly proportional to the coating thickness.

There are a variety of fastener finishes to protect from corrosion, achieve a special property or to improve appearance. Each plating material and finish has its own properties relating to appearance, ability to resist corrosion and ability to reduce friction. So as a recap, in the Aerospace Fastener Industry, a coating should be able to coat corrosion resistant materials such as: titanium alloys, corrosion-resistant steels, nickel based alloys, prevent galvanic corrosion between fasteners and aluminum alloy structures, provide lubrication for thread friction and for interference fit assembly, resist aggressive chemicals (paint strippers, jet fuel, hydraulic fluids, cleaning solvents), provide ductility which prevents cracking caused by part expansion or contraction of the substrate or shock, adhere strongly to the aircraft's external paint scheme and the sealant, and most of all be environmentally friendly. Cadmium used to be the industry’s go-to coating compound up until its toxicity raised wide concerns. The same happened with Chromium and Chromate based compounds. Silver is an excellent coating, but it is not cost effective. The industry has now moved on to new coatings that do not make use of heavy metals and toxic compounds such as Molybdenum Disulphide, Cetyl Alcohol, Antimony and Lead, yet meet the same levels of lubricity, resistivity and affordability as highlighted by industrial standards.

The Recess -

In the late 1990s, Dassault Aviation, an international French aircraft manufacturer of military, regional, and business jets, a subsidiary of Dassault Group, were developing their first ever aircraft using composite, a material that had seldom been used before and also one that had severely different physical characteristics compared to the traditional metallic structure of an aircraft. The composite which was predominantly being used at the time in the field of aerospace was CFRPs which stands for Carbon Fiber Reinforced Polymers. In the most rudimentary sense, the composite structure is an extremely strong and light fiber-reinforced plastic which contains carbon fibers. CFRPs can be expensive to produce but are commonly used wherever high strength-to-weight ratio and rigidity are required, such as aerospace, automotive, civil engineering, sports goods and an increasing number of other consumer and technical applications. The binding polymer is often a thermoset resin such as epoxy, but other thermoset or thermoplastic polymers, such as polyester, vinyl ester or nylon, are sometimes used. The composite may contain aramid (e.g. Kevlar, Twaron), aluminum, ultra-high-molecular-weight polyethylene (UHMWPE) or glass fibers in addition to carbon fibers.

CFRPs are composite materials. In this case the composite consists of two parts: a matrix and reinforcement. In CFRPs the reinforcement is carbon fiber, which provides the strength. The matrix is usually a polymer resin, such as epoxy, to bind the reinforcements together. Because CFRPs consists of two distinct elements, the material properties depend on these two elements. The reinforcement will give the CFRPs its strength and rigidity; measured by stress and elastic modulus respectively. Unlike isotropic materials like steel and aluminum, CFRPs has directional strength properties. The properties of CFRPs depend on the layouts of the carbon fiber and the proportion of the carbon fibers relative to the polymer. The two different equations governing the net elastic modulus of composite materials using the properties of the carbon fibers and the polymer matrix can also be applied to carbon fiber reinforced plastics. The following equation,

$$E_c = V_m E_m + V_f E_f$$

is valid for composite materials with the fibers oriented in the direction of the applied load. is the total composite modulus, are the volume fractions of the matrix and fiber respectively in the composite and are the elastic moduli of the matrix and fibers respectively. The other extreme case of the elastic modulus of the composite with the fibers-oriented transverse to the applied load can be found using the following equation:

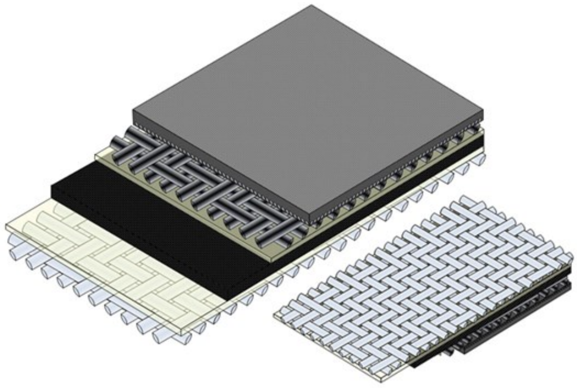
$$E_c = \left(\frac{V_m}{E_m} + \frac{V_f}{E_f} \right)^{-1}$$

The fracture toughness of carbon fiber reinforced plastics is governed by the following mechanisms:

1) debonding between the carbon fiber and polymer matrix

2) fiber pull-out

3) delamination between the CFRPs sheets.



Typical epoxy-based CFRPs exhibit no plasticity, with less than 0.5% strain to failure. Although CFRPs with epoxy have high strength and elastic modulus, the brittle fracture mechanics present unique challenges to engineers in failure detection since failure occurs catastrophically. As such, recent efforts to toughen CFRPs include modifying the existing epoxy material and finding alternative polymer matrix. One such material with high promise is PEEK, which exhibits an order of magnitude greater toughness with similar elastic modulus and tensile strength. However, PEEK is much more difficult to process and more expensive.

Despite its high initial strength-to-weight ratio, a design limitation of CFRPs is its lack of a definable fatigue endurance limit. This means, theoretically, that stress cycle failure cannot be ruled out. While steel and many other structural metals and alloys do have estimable fatigue endurance limits, the complex failure modes of composites mean that the fatigue failure properties of CFRPs are difficult to predict and design for. As a result, when using CFRP for critical cyclic-loading applications, engineers may need to design in considerable strength safety margins to provide suitable component reliability over its service life.

Environmental effects such as temperature and humidity can have profound effects on the polymer-based composites, including most CFRPs. While CFRPs demonstrate excellent corrosion resistance, the effect of moisture at wide ranges of temperatures can lead to degradation of the mechanical properties of CFRPs, particularly at the matrix-fiber interface. While the carbon fibers themselves are not affected by the moisture diffusing into the material, the moisture plasticizes the polymer matrix. The epoxy matrix used for engine fan blades is designed to be impervious against jet fuel, lubrication, and rain water, and external paint on the composites parts is applied to minimize damage from ultraviolet light.

In the most rudimentary form, new age aerospace structural materials such as CFRP are a material made of layers unlike its metallic counterparts such as aluminum alloys that are one homogenous piece. When it came to fastening the metallic structural elements in the aerospace industry, a special type of fastener known as the interference fit fastener had been consistently been used and it sufficiently performed all the functions it was intended for.

An interference fit, also known as a press fit or friction fit is a fastening between two parts which is achieved by friction after the parts are pushed together, rather than by any other means of fastening.

The tightness of fit is controlled by amount of interference; the allowance (planned difference from nominal size). Formulas exist to compute allowance that will result in various strengths of fit such as loose fit, light interference fit, and interference fit. The value of the allowance depends on which material is being used, how big the parts are, and what degree of tightness is desired. Such values have already been worked out in the past for many standard applications, and they are available to engineers in the form of tables, obviating the need for re-derivation.

As an example, a 10 mm (0.394 in) shaft made of 303 stainless steel will form a tight fit with allowance of 3–10 µm (0.0001–0.0003 in). A slip fit can be formed when the bore diameter is 12–20 µm (0.0005–0.0008 in) wider than the rod; or, if the rod is made 12–20 µm under the given bore diameter.

An example: The allowance per inch of diameter usually ranges from 0.001 inch to 0.0025 inch (0.1–0.25%), 0.0015 inch (0.15%) being a fair average. Ordinarily the allowance per inch decreases as the diameter increases; thus, the total allowance for a diameter of 2 inches (50.8 mm) might be 0.004 inch (0.102 mm, 0.2%), whereas for a diameter of 8 inches (203.2 mm) the total allowance might not be over 0.009 or 0.010 inch (0.23 or 0.25 mm, i.e. 0.11–0.12%). The parts to be assembled by forced fits are usually made cylindrical, although sometimes they are slightly tapered. Advantages of the taper form are: the possibility of abrasion of the fitted surfaces is reduced; less pressure is required in assembling; and parts are more readily separated when renewal is required. On the other hand, the taper fit is less reliable, because if it loosens, the entire fit is free with but little axial movement. Some lubricant, such as white lead and lard oil mixed to the consistency of paint, should be applied to the pin and bore before assembling, to reduce the tendency toward abrasion.

There are two basic methods for assembling an oversize shaft into an undersized hole, sometimes used in combination: force and thermal expansion or contraction.

There are at least three different terms used to describe an interference fit created via force: press fit, friction fit, and hydraulic dilation.

Press fit is achieved with presses that can press the parts together with very large amounts of force. The presses are generally hydraulic, although small hand-operated presses (such as arbor presses) may operate by means of the mechanical advantage supplied by a jackscrew or by a gear reduction driving a rack and pinion. The amount of force applied in hydraulic presses may be anything from a few pounds for the tiniest parts to hundreds of tons for the largest parts.

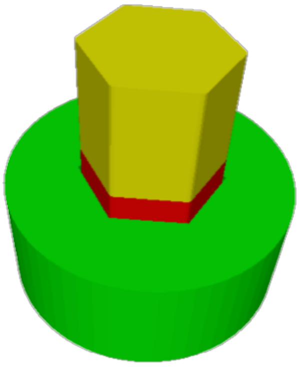
Often the edges of shafts and holes are chamfered (beveled). The chamfer forms a guide for the pressing movement, helping to distribute the force evenly around the circumference of the hole, to allow the compression to occur gradually instead of all at once, thus helping the pressing operation to be smoother, to be more easily controlled, and to require less power (less force at any one instant of time), and to assist in aligning the shaft parallel with the hole it is being pressed into. In the case of train Wheelsets, the wheels are pressed onto the axles by force.

Most materials expand when heated and shrink when cooled. Enveloping parts are heated (e.g., with torches or gas ovens) and assembled into position while hot, then allowed to cool and contract back to their former size, except for the compression that results from each interfering with the other. This is also referred to as shrink-fitting. Railroad axles, wheels, and tires are typically assembled in this way. Alternatively, the enveloped part may be cooled before assembly such that it slides easily into its mating part. Upon warming, it expands and interferes. Cooling is often preferable as it is less likely than heating to change material properties, e.g., assembling a hardened gear onto a shaft, where the risk exists of heating the gear too much and drawing its temper.

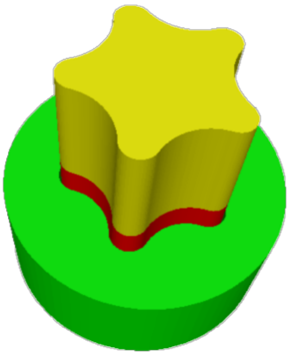
So, in the case of composites like CFRP, the traditional interference fastening system is not an option as the threads on an interference fastener upon being hammered would disrupt the layers of the CFRP and any structural deformation in an aircraft could bring about cataclysmic damages, both monetarily and in terms of lives as well. So with composites, a different type of fastening systems were introduced – the clearance fit fastening system, where unlike the interference fit fastening system, the diameter for the holes for the fastener were larger than the diameter of the fastener itself. This permitted the fastening to almost "slide" into the fastening hole without any real need to input any form of pressure and also eliminate any opportunity for any deformity to strike the structural integrity of the composite.

Yet there is one huge issue that comes with there not being any interference, a severe loss of torque. Dassault Aviaion being an aircraft manufacturer needed fasteners that could withold severe amounts of pressure and force without any sort of failure, which implies that there has to be the perfect amount of torque in each fastening, but the fact remained that since their fasteners were now being used to conjoin composites, and all the interference torque was lost, a lot of torque had to be generated from somewhere and the Hex bolt just was not efficient enough in being able to transfer that much torque without wearing out the recess. Point-to-surface contact between Hex drive tool and fastener head often led to rapid tool wear and distorted the fastener head as the torque increased. A 60° drive angle is inefficient for torque transfer as stress is concentrated at corners of Hex socket, which can caused the socket to fail at these stress points. On top of that the diameter of the Hex drive socket is normally greater than the bearing surface of fastener, forcing engineers to design for socket clearance. That's where the fastening industry's need to create its first big breakthrough in decades arose.

To efficiently transfer torque to make up for that which was lost in the shift from interference fit to clearance fit fasteners, a new recess had to be developed. First developed by LISI Aerospace and patented in the 1990s, the Aster® Recess System was specifically designed to provide a simple, cost- effective solution to the problems inherent in the process of installing and removing fasteners for the CFRP based Aerospace structural bodies. The Aster® Recess System drastically improved torque efficiency, enhanced product reliability, increased productivity, and reduced total assembly costs.



The Hex Recess

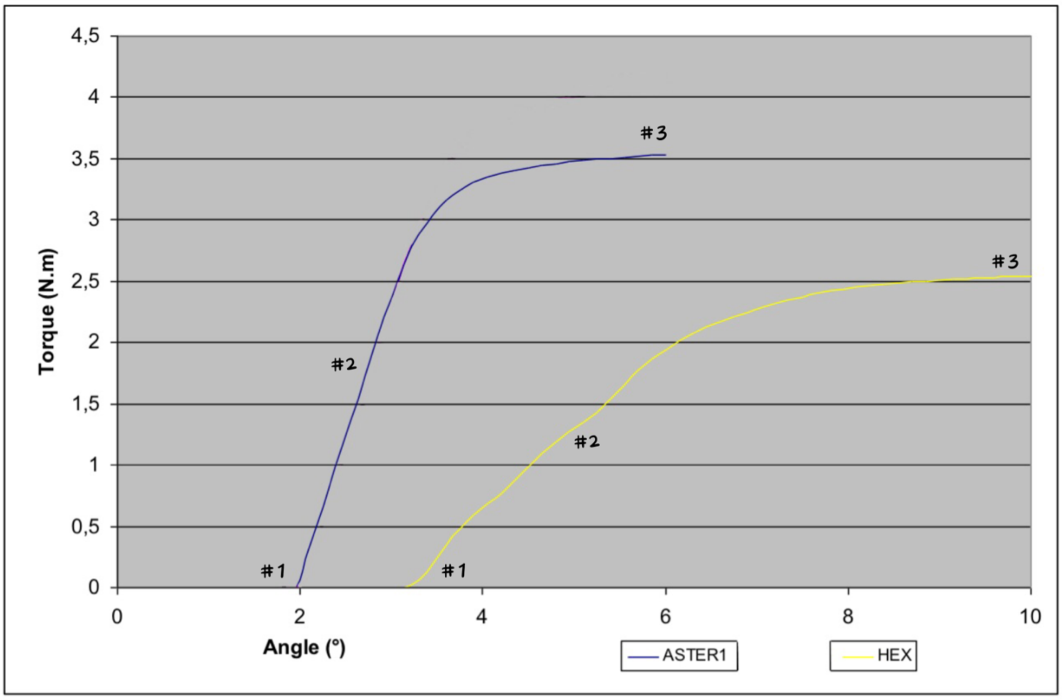


The Aster® Recess

Compared to Hex recess with its 60° drive angle, the Aster® Recess with its 18° drive angle provided a much higher torque transfer efficiency, meaning the amount transferred per rotation became exponentially higher as seen below.

As represented in the data collected in the Torque vs. Rotational Angle graph below, we see that the contact time for the Hex Recess appears far later than that of the Aster® Recess highlighted by **#1**. As explained earlier, the “stiffness” of the curve is lower for Hex Recess than the Aster® Recess, i.e, to transmit the same torque, a higher rotation would be needed and therefore deformation would be caused to Hex rather than Aster shape highlighted by **#2**. Furthering upon the previous point we can also see that rotational angle for the Hex Recess is almost two times that of the Aster® Recess. And finally as seen by **#3**, the inflection point, i.e, the start of permanent deformation of the recess is much higher for the Aster® Recess that the Hex Recess.

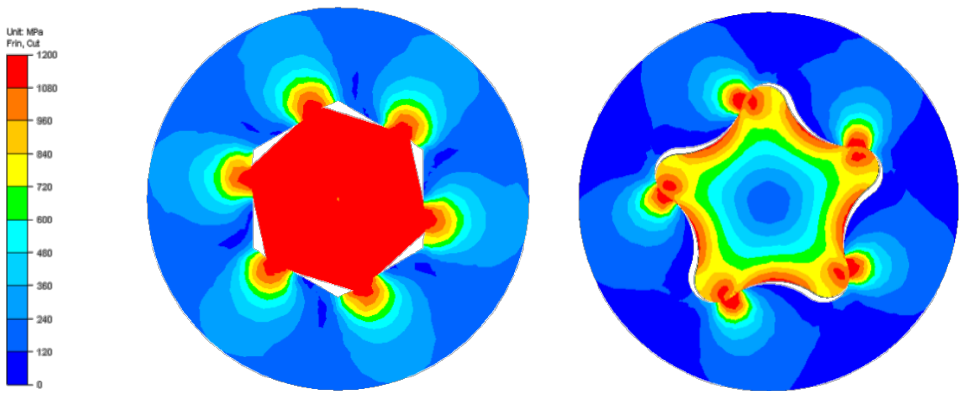
<u>Torque vs. Rotational Angle</u>



The Aster® Recess System, with its broader surface area, provides greater depth of lobe engagement between the driver and the fastener, allowing driving forces to spread over a broader surface, as opposed to the point contact of many drive systems. This makes the Aster® Recess System also mechanically superior and nearly impossible to strip extending the screw and bit's life.

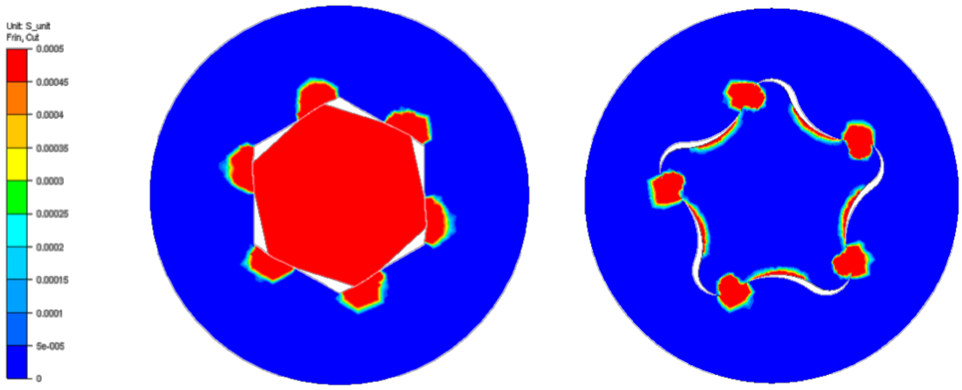
This is highlighted below where we see the highest stress appears in the contact area for both the Hex Recess System and the Aster® Recess System. However the Hex Recess

System is clearly overloaded at this torque level whereas the Aster® Recess System withstands the torque level sufficiently.



The Hex Recess The Aster® Recess

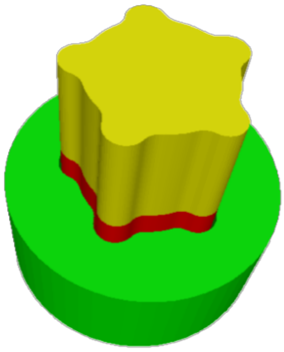
Elaborating upon the previous point, permanent deformation to the Recesses is almost tackled in the same way, where we see the permanent deformation appears in the contact area for both the Hex Recess System and the Aster® Recess System. However the Hex Recess System is clearly suffering irreversible damage especially to its Drive System as compared to the Aster® Recess System, as shown below.



The Hex Recess The Aster® Recess

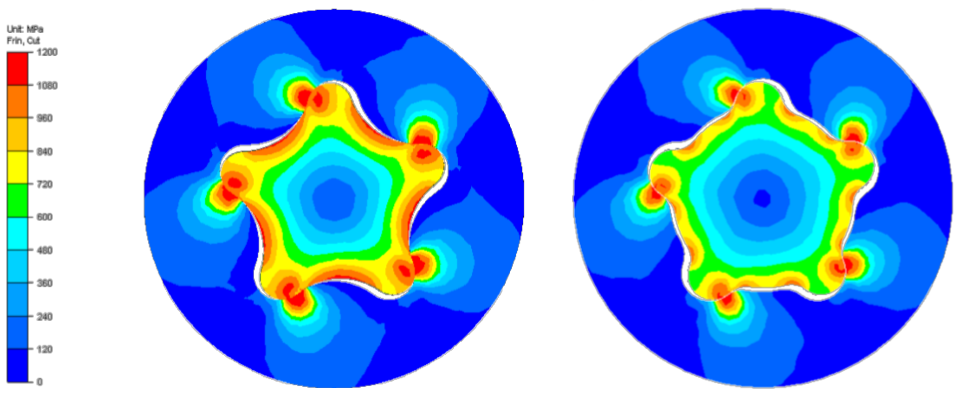
Also with its vertical sidewalls, the Aster® Recess increases tool engagement, unlike cruciform drive systems, no camout forces are created to push the driver up and out of the fastener. Since camout is virtually eliminated, little or no end load is required, meaning theoretically the Aster® Recess System can reduce fatigue and muscular stress during the manual assembly of fasteners. The fact that the Aster® Recess completely encloses its drive bit, means one would be minimizing tool slippage, the damage and injuries it could cause.

As is clearly visible from all the diagrams covered thus far, the Aster® Recess has concave curve in between each of its five pins. This was the first iteration of the Aster®. In order to even further maximize the features the first iteration of the Aster® without compromising the actual structure itself, the second iteration of the Aster® was created. This involved the use of a convex curve in between each of its five pins.



The Second Iteration Aster® Recess

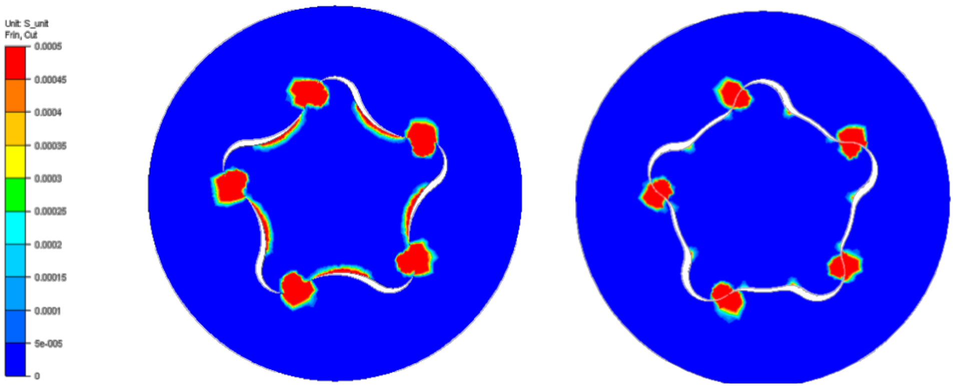
This either retained or furthur maximized all of the first iteration Aster®'s original features by increasing the surface area of the contact area making for an even better rendition of the Aster Recess as shown below.



The First Iteration Aster® The Second Iteration Aster®

Shown above is the highest stress instances in both the Asters®. The Second Iteration Aster® holds out far better than its First Iteration Counterpart solely due to the clear increase in contact surface area, i.e, the Torque force is spead over a largee area thus minimizing the stress.

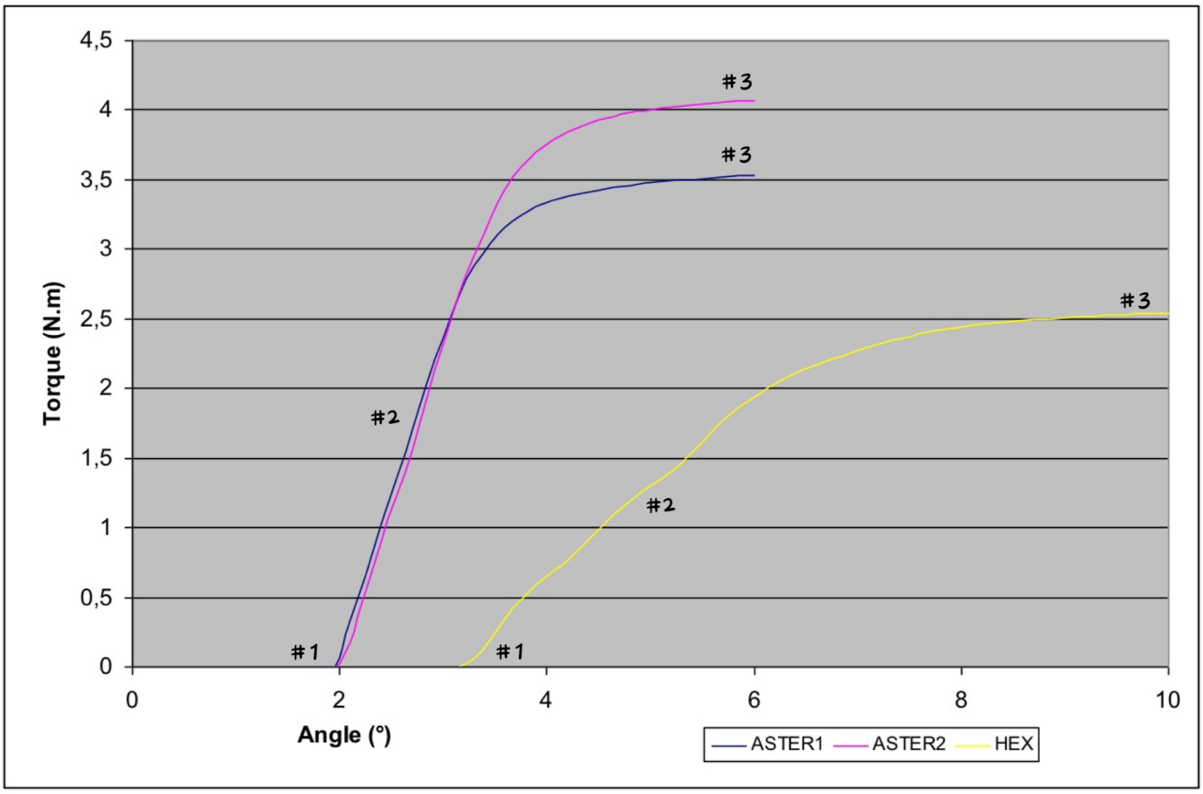
In much the same way, as shown below we see the First Iteration Aster® is deformed permanently at a larger scale at the same amount of Torque force as compared to its Second Iteration counterpart.



The First Iteration Aster®   The Second Iteration Aster®

As represented in the data collected in the secondary Torque vs. Rotational Angle graph below, we see that the contact time for the Aster® Recesses is about the same amount of time as highlighted by **#1**. As explained earlier, the “stiffness” of the curve for the Aster® Recesses is about the same, i.e, to transmit the same torque, the same rotation would be needed and therefore the same deformation would be caused to the Aster shapes as highlighted by **#2**. However, finally as seen by **#3**, the inflection point, i.e, the start of permanent deformation of the recess is much higher for the Second Iteration of the Aster® Recess as it is for the first only validating the points made in the previous two paragraphs.

Torque vs. Rotational Angle



The Aster® Recess fundamentally overcomes every one of the drawbacks of the standard Hex Recess, thus, making it one of the most commonly found Aerospace fasteners on the Market. One might compare it to the Torx® Recess, but a recess with an even number of pins has a far higher camming-out rate than a recess with an odd number of pins, making the Aster® a superior product. One might also question the number of odd recesses, as to why could not there be seven or more pins. If the number of pins would increase, the cost of manufactring each piece would increase as there would be multiple more intricacies yet the change in features would be negligible thus not providing anyone with any incentive to manufacture a fastener of that sort.

The Aster® is the new industrial standard for Aerospace Fasteners. It will be years before another breakthrough of this magnitude is bought about. The Aster® is safe, reliable, and functional. It saves millions of dollars in the long run and has definitely proved itself to be **“Next Big Step in the Evolution of the Aerospace Fasteners”**.

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