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New Lock Washer Technology Replaces Safety Wire in Many Applications

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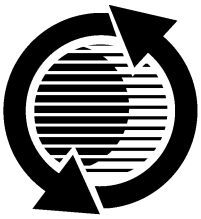
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ABSTRACT

Aircraft and military ground vehicles are exposed to extreme environmental conditions, not the least of which is vibration. Safety and reliability considerations have led to a variety of locking mechanisms. Until recently, the most effective solution for securing switches, sensors, hydraulic actuators and many other external components was safety wire. A new locking washer concept has been developed that provides safety, quality and cost advantages over safety wire for many of these applications. This concept has found use in military land vehicles, helicopters and aircraft including over 400 fastening applications on the F-22 fighter.

INTRODUCTION

We will begin by exploring how and why did this new development come about. Krezak, in his paper “Implementation of New Fasteners Into Production” [1], contends there are three fundamental forces which drive the development and implementation of a new device in aircraft manufacturing. They are new design requirements, cost of the fasteners, and cost of the installation. He further states that “The common denominator for all participants, and the key factor to implementation of new fastener systems lies in defining a need.”

Several factors, or needs, for improved fastening technology have existed for some time. The first and most important is safety. Think about the Wright brothers who designed, built and flew their own aircraft. For them, safety was a real issue. But, unlike most of us, every aspect of safety was directly under their control. Today, there are a few brave soles who design, build and fly their own aircraft. The rest of us rely on the performance of thousands of people to assure air travel safety. Fortunately, it is a system that works. We have all heard data reporting commercial air travel to be safer than automobile travel. What’s more, aviation safety is improving. The Federal Aviation Administration reports [2] that total accidents per 100,000 hours flown dropped from 10.91 total occurrences in 1982 to 7.98 in 1991. Never the less, when human lives are at stake, we continue to strive for safety advancements, particularly those that can simplify aircraft construction and maintenance.

Quality, too, is paramount. One widely accepted definition of quality is “fitness for use.” New military requirements prohibit the use of safety wire because pigtails can penetrate biochemical protective clothing. Clearly, this old standby is no longer fit for use in some applications. Another definition of quality is “customer satisfaction.” The customers who first come to mind are the pilots and passengers, but the mechanics and technicians who assemble and maintain aircraft are also customers. As highly trained as they are, they still bear a huge burden of responsibility, and engineers have an obligation provide them with the highest quality components and processes.

Quality improvement principles have been extensively applied in the aircraft industry. One methodology, called “error proofing,” is described by Juran [3]. Examples are fail-safe systems and alarms. He also describes “Pokayoke,” the error proofing principles credited to the Japanese. The Pokayoke principles are: 1) eliminate the possibility of error, 2) substitute a more reliable process, 3) make the work easier to perform, 4) detect the error before further processing and 5) minimize the effect of the error. It will be shown that a new safety-fastening concept has been developed through application of these other quality improvement principles.

The last incentive for developing improved fastening technology is cost. Everything else being equal, cost is no object when human lives are at stake. However, today’s quality movement identifies cost reduction as a benefit of quality improvement [4]. When a less costly alternative of equal or greater safety and quality is developed, it should be used.

ENVIRONMENTAL FASTENING ISSUES

Three primary environmental issues come into play for aircraft fastening reliability. The first and most challenging is vibration because it can lead to fatigue failure. The second is temperature fluctuation (i.e. thermo-cycling), that can lead to tensile or fatigue failure. The third, corrosion, can result from external exposure to water and chemicals

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and from galvanic reaction between the components of a fastening system. Corrosion can also lead to both tensile and fatigue failure.

For these reasons, and others that will be addressed, fastening security methods commonly used in other applications are totally unsuitable. These include various distressed thread designs and chemical locking.

A BRIEF HISTORY OF FASTENER SAFETY

It is not within the scope of this paper to present a comprehensive history of fastener safety, but rather an overview of this subject as it relates to aircraft. Most of the early activity associated with transportation was in the railroad industry. Between 1869 and 1905, the U.S Patent Office awarded six patents for washer-type locking devices used to join rails [5] [6] [7] [8] [9]. Examples of these inventions are shown in Figure 1. These designs addressed some of the same environmental issues already discussed, vibration and temperature extremes, but not to the same levels of intensity. While simple to manufacture and use, none of these designs are suitable for aircraft. Ironically, however, through design innovation, the general locking washer concept has recently proved suitable.

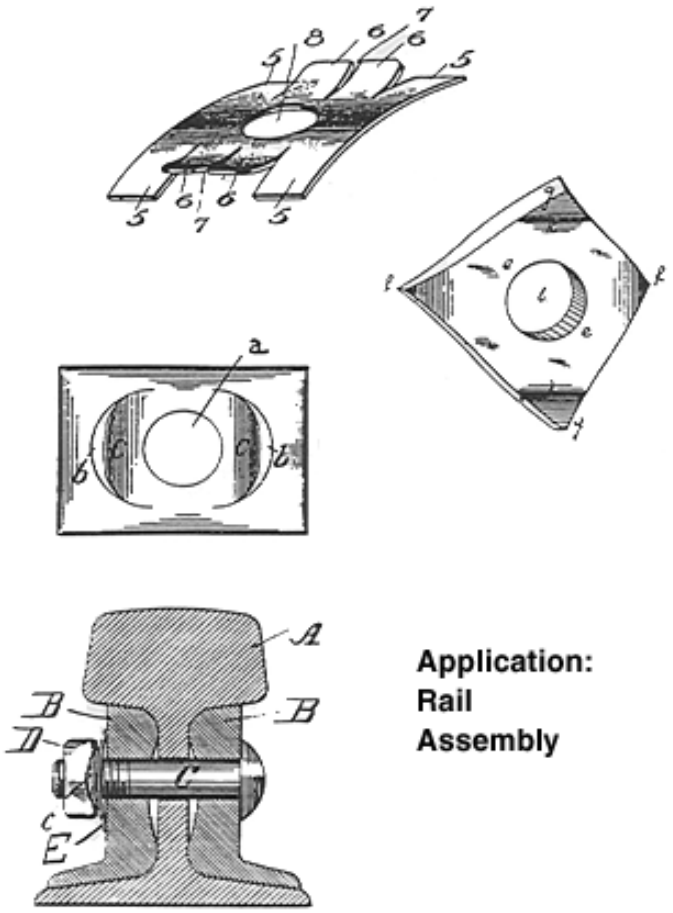


Figure 1. Railroad Locking Washers

Over the years, the National Aeronautics and Space Administration has disseminated numerous technological developments, encouraging their use throughout industry. A document entitled “Fasteners and Fastening Technique,” NASA SP-5903 (03) [10] identifies 26 aerospace fastening concepts. Most of the designs are complex and relatively expensive. Few are applicable to component fastening except for the single-unit locking device is shown in Figure 2.

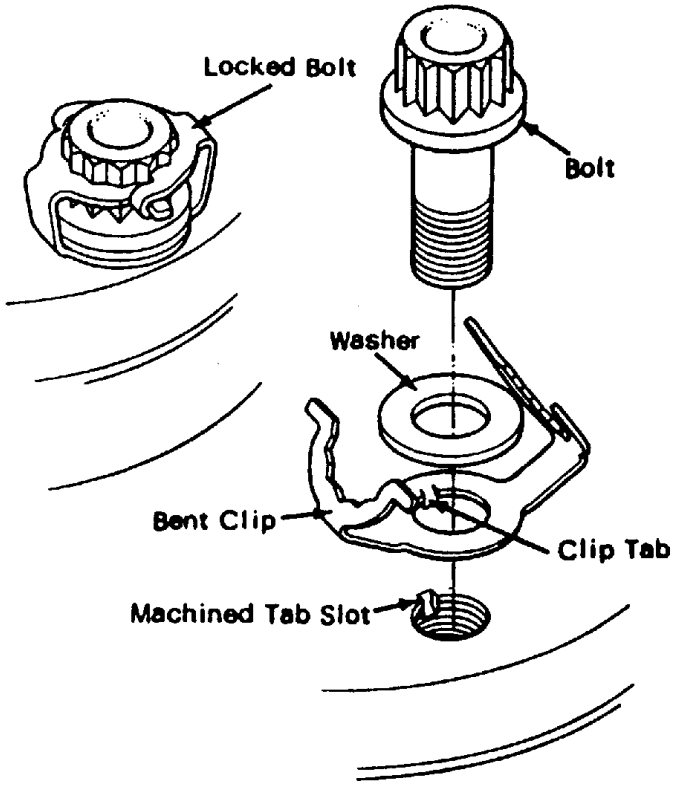


Figure 2. Single-Unit Locking Device

This device, however, has its limitations. Most notably, it requires precise orientation to engage the locking features, and it cannot be reused.

We will now move on to safety wire. Rather than discuss its origin, the authors will simply state obvious. It has been around for a long, long time. For the applications being addressed, it has been the fastener safety design of choice.

MAINTENANCE REQUIREMENTS FOR FASTENERS

Enser [11] identified what he called the “ilities” of fastener technology as critical issues. These are producibility, reusability, maintainability, and reliability. Church [12] expanded on these issues stating that “Airline and accessory builders can cut airline operating costs by more careful selection of fasteners and fastening methods” and that those fasteners should be simple. He cited twelve factors to consider when selecting aircraft fasteners, and presented them in this approximate order of importance:

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1. **Performance** – A fastener must perform its intended job.
2. **Reliability** – It must function without failure for the life of the aircraft or component.
3. **Safety** – Both of the aircraft and of the people that use the fasteners.
4. **Standardization** – Each fastener should be a recognized industry-wide standard part.
5. **Availability** – Replacement should be readily available from several reliable sources.
6. **Ease-Of-Use** – Avoid tricky operations that are not readily discernable by the user
7. **Reasonable Cost** – The cost should be commensurate with the function, and with that of competitive items.
8. **Interchangeability** – Selective fit should not be required.
9. **Tooling** – Tools must be adequate, available, reasonably trouble-free, and simple to use.
10. **Corrosion Control** – Environment, dissimilar metals, and stress levels need to be considered.
11. **Reusability** – Is the fastener re-useable? How many times? How can you tell?
12. **Identification** – The fastener's part number must be readily discernable.

SAFETY WIRE AND IT'S ROLE IN AVIATION

Safety wire is an important technology that has contributed to aircraft safety. Numerous, safety-related fastening applications are secured by safety wire. These include external switches, sensors and actuators that are vital to aircraft function.

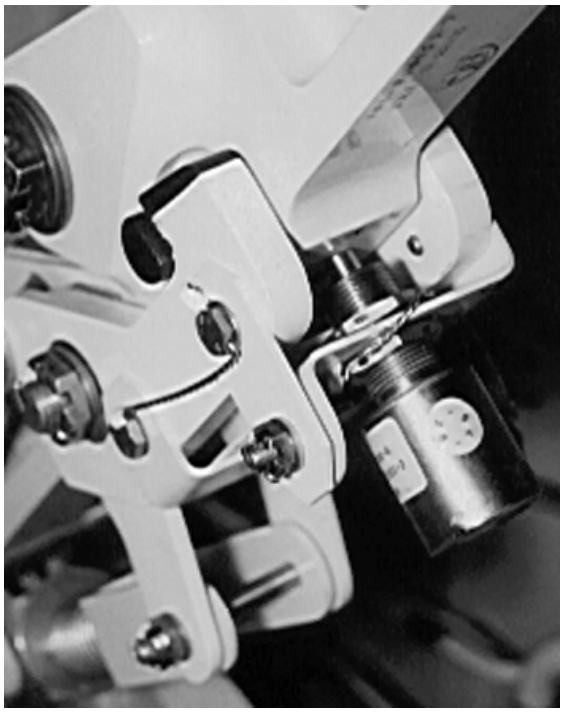


Figure 3. Main Landing Gear Downlock Switch

Figure 3 shows safety wire securing the mounting nuts of a main landing gear download switch. In Figure 4, safety wire is securing fasteners as part of a landing gear brake assembly.



Figure 4. Landing Gear Brakes

The Engineering Society for Advancing Mobility Land Sea Air and Space (SAE) has published Aerospace Standard AS567 entitled "Safety Cable, Safety Wire, Key Washers, and Cotter Pins For Propulsion Systems, General Practices For Use Of" [10]. This document has been accepted as the American National Standard. It gives application data such as preferred sizes, wire material chemistry and installation techniques. Special emphasis is placed on issues that are critical to safety wire function

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and reliability. Several paragraphs form this standard, are presented here verbatim.

3.1.6 – Caution must be exercised during the twisting operation to keep the wire taut. Gripping surfaces of pliers shall have edges sufficiently rounded to preclude nicks. Abrasions and scratches are allowed; however, nicks are not allowed.

3.1.7 – Exercise caution when installing safety wire on parts subject to relative movement such that the wire itself is not chafed, fatigued through vibration, installed over radii less than .005 in (0.13 mm) or given additional tension other than tension imposed on the wire to prevent loosening.

3.1.9 – Safety wire shall be new upon each application.

3.2.1.1 – Prior to installation assure the units to be safety wired have been tightened to the correct torque. Undertorquing or overtorquing to obtain proper alignment of the holes is not permitted. If it is impossible to obtain a proper alignment within the specified torque limits, back off the unit and try it again, select another unit, or try another wire method.



Figure 5

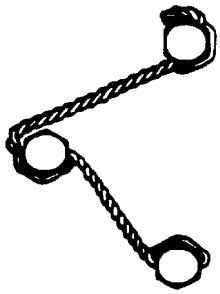


Figure 6

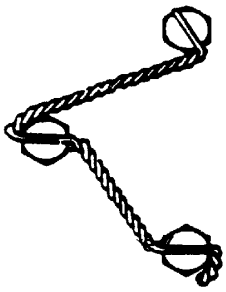


Figure 7



Figure 8

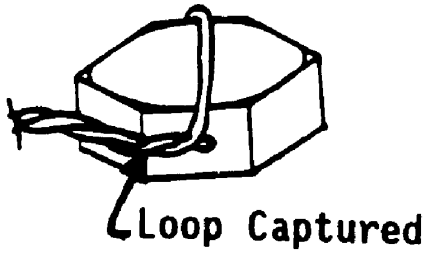
Figure 5. Safety Wire Configurations

3.2.1.2 – In adjacent units, it is desirable that the holes be in approximately the same relationship to each other as shown in Figure 5 through 8 [Figure 5 above] for right-hand threads, and the safety wire shall be installed in such a manner that the strand through the hole will have a tendency to pull the unit clockwise should the unit loosen. This should be reversed for left-hand threads.

3.2.1.3 – For installation where the loop is not captured from movement and movement of the loop itself could cause the wire to loosen, the portion of the wire that exits the hole in the unit shall be twisted over the top of the wire that extends around the unit [Figure 6 below].

3.3.1.1 – All external safety wire shall be inspected visually for drawing conformity prior to shipment. Specific areas of inspection are as follows: a. Broken wire, b. Direction of strand, c. Total flex, d. Pigtail length, e. Pigtail position f. Loose part(s) on or within safety wire.

3.3.1.2 – Strands of twisted or single wire between parts shall not be broken or violate the kink and nick criteria of 2.3.2, 2.3.3, and Figure 2 [Figure 7 below].



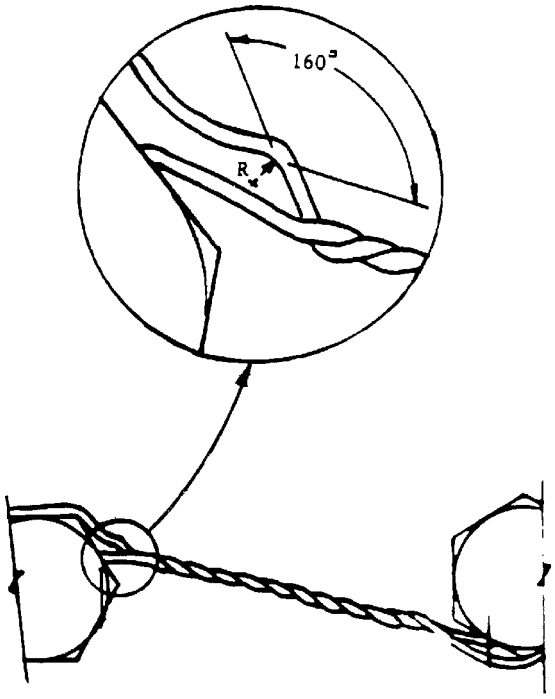
ACCEPTABLE



NOT ACCEPTABLE

Figure 6. Safety Wire Strand Orientation

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1. **Kink radious to be equal to or less than wire radius.**

2. **Kink angle to less than 60 degrees.**

Figure 7. Safety Wire Kink

It is not the authors' intent to cast doubt and concern over the use of safety wire. It has proven its effectiveness. But, as this standard indicates, considerable care must be taken to assure a proper installation. Maintenance technicians use specialized tools that require daily calibration. Furthermore, visual inspection can be difficult and time consuming. The opportunities to apply the principles of Pokayoke should now be apparent.

AN IMPROVED LOCKING WASHER CONCEPT

Endres describes two basic methods of process improvement in his paper "An Aerospace Manufacturing Improvement Process" [13]. They are Kaisen and innovation. Kaisen, or continuous improvement, results from ongoing efforts to make something better. Innovation involves large-scale change, which produces a totally new design or process. He further states that improvements normally involve both components. It was, in fact, the simultaneous application of these techniques that led to the improved locking washer design described below. Kaisen was applied to develop a locking washer design with significant advantages over prior art, and innovation led to the application of this technology to many safety-wire applications.

The new, patented locking washer technology that was developed is being produced under the trade name REALLOCK™. It has been engineered for a variety of fastening system applications, from standard military electrical connectors to elaborate, multi-fastener systems. Each REALLOCK™ is a thin metal device that typically incorporates two features. The first is an anti-rotation feature, and the second is a unique locking tab design. Figure 8 shows a basic REALLOCK™ washer.

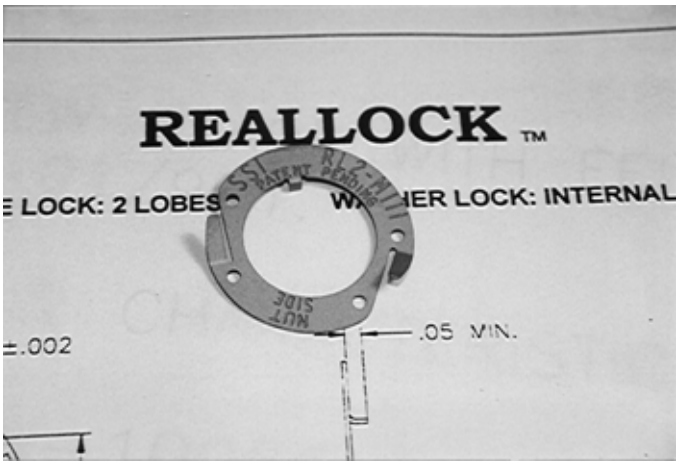


Figure 8. Basic REALLOCK™ Washer

As shown in Figure 9, REALLOCK™ can be easily installed and removed with socket, open-end or box wrenches. Once installed, one of the lobes prevents the nut from losing the clamp load. The other lobe acts as a bias to the nut preventing possible "rattling."

There are many other benefits associated with REALLOCK™. It can be visually inspected, and it can be reused repeatedly. Its use reduces assembly time, maintenance time, parts inventories, weight and contamination potential.

As shown in Figure 10, a REALLOCK™ locking washer can even be designed with a grounding tab that eliminates the need for grinding or polishing to achieve electrical continuity.

Another important advantage over other safety locking concepts is that REALLOCK™ does not require orientation. The multiple lobes have been statistically toleranced and engineered. There is no need to apply additional nut torque, or to back off the nut, in order to align the locking lobes. With the REALLOCK™ design, one lobe is always raised to prevent the nut from backing off while the other the other remains under the nut for bias. The fact that there are two lobes also provides redundant locking. When rotated less than 30 degrees, the lobes reverse their roles. Figure 11 illustrates how this works.

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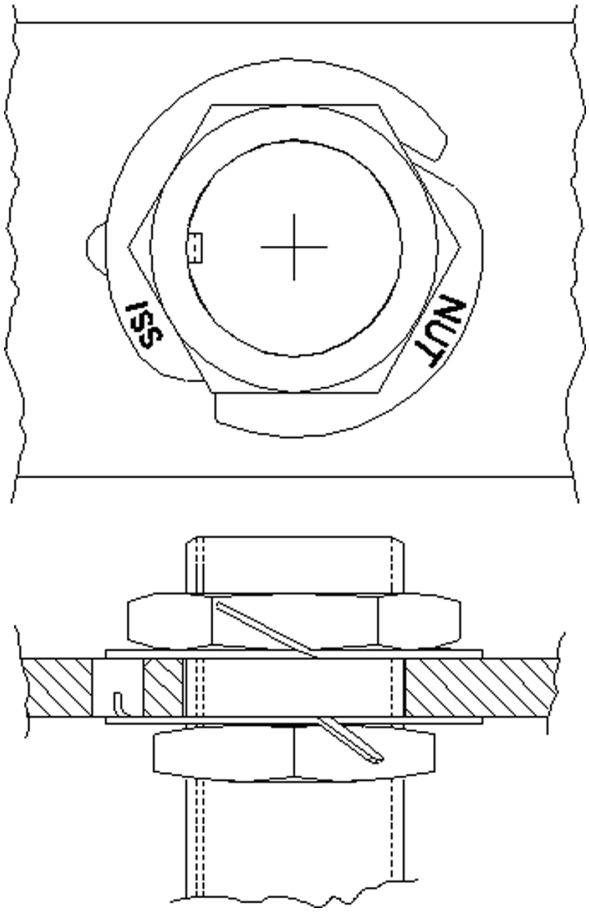


Figure 9. REALLOCK™ Assembly

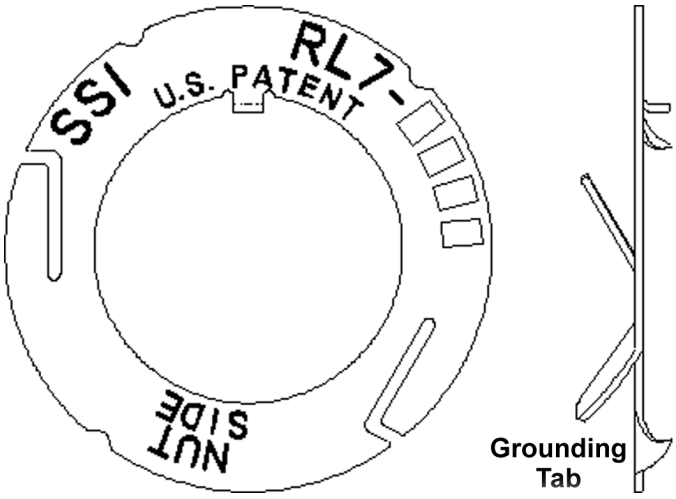


Figure 10. REALLOCK™ Grounding Tab Feature

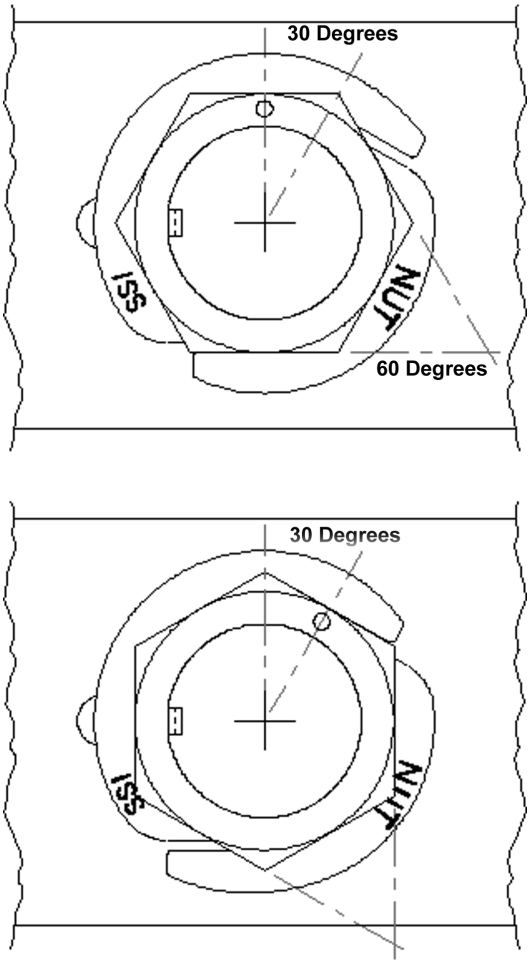


Figure 11. REALLOCK™ Locking Lobes

By understanding and applying this locking washer technology to components and fastening, designers have a simple means of assuring total system quality and performance.

COMPARISON TO SAFETY WIRE

The benefits of REALLOCK™ versus safety wire will first be analyzed using Esner's criteria (6):

1. **Performance** – In vibration environments where REALLOCK™ has been tested, it has proven to meet performance requirements. It prevents the nut from backing off even with the loss of joint clamp load. After carefully evaluating and its performance, Lockheed has approved REALLOCK™ for the F-22 fighter.
2. **Reliability** – The extensive and detailed installation procedures outlined in SAE AS567 are required to assure reliability and performance of safety wire. These are all eliminated with REALLOCK™ because installation is identical to a typical non-locking washer. What's more, simple visual inspection assures REALLOCK™ reliability.
3. **Safety** – In recent years, emphasis on maintainability and safety in hostile environments has increased, and new military requirements prohibit the use of

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safety wire because pigtails can penetrate biochemical protective clothing. Further, injuries such as piercing the skin, which occur with safety wire during installation, are eliminated with REALLOCK™.

4. **Standardization** – Safety wire has long been the standard for many aircraft fastening applications, as its basic operating principle does not vary with fastener size or joint configuration. REALLOCK™ clearly achieves this principle as well.
5. **Availability** – REALLOCK™ locking washers are resusable, but they also take up far less storage space so they can be more easily inventoried. Each time a component fastened and secured with safety wire is serviced, the wire must be replaced. Special tools are required for this process.
6. **Ease-Of-Use** – The precision and detail if the instructions for the usage of safety wire in SAE SA567 clearly implies the difficulties associated with its installation experienced over the years. These conditions are completely eliminated with REALLOCK™ because installation is identical to the typical non-locking washer.
7. **Reasonable Cost** – Assembly and inspection time is reduced. Cost is fixed with the acquisition expense, and is not variable with material and labor.
8. **Interchangeability** – The safety wire hole alignment issue addressed in paragraph 3.2.1.1 of SAE AS567.1.1, which may require that particular fasteners be discarded, does not exist with REALLOCK™.
9. **Tooling** – Unlike with safety wire, no special tools are required.
10. **Corrosion Control** – Washers can be fabricated in stainless steel and can also be plated to avoid galvanic corrosion.
11. **Reusability** – Washers can be reused many times: safety wire must be replaced with each use.
12. **Identification** – Part identification is included on the surface of each washer.

Next, let us evaluate REALLOCK™ against the error proofing principles of Pokayoke.

1. **Eliminate the possibility of error** – The potential errors associated with safety wire are eliminated.
2. **Substitute a more reliably process** – Simplicity contributes to process reliability.
3. **Make the work easier to perform** – Installation, inspection, and service are all easier.
4. **Detect the error before further processing** – Errors are more easily detected through visual inspection.
5. **Minimize the effect of the error** – No claims are made in this regard. This principle is typically applied to the system in question which includes the component being fastened and its function.

APPLICATIONS

REALLOCK™ is being used on several helicopters and aircraft, including over 400 fastening applications on the F-22 fighter. It is also found use in military land vehicles. It can be engineered into many configurations, including multi-fastener systems. As the number of fasteners in the assemble increases, so does the time and cost savings relative to safety wire. Examples of alternate configurations are shown in Figure 12.

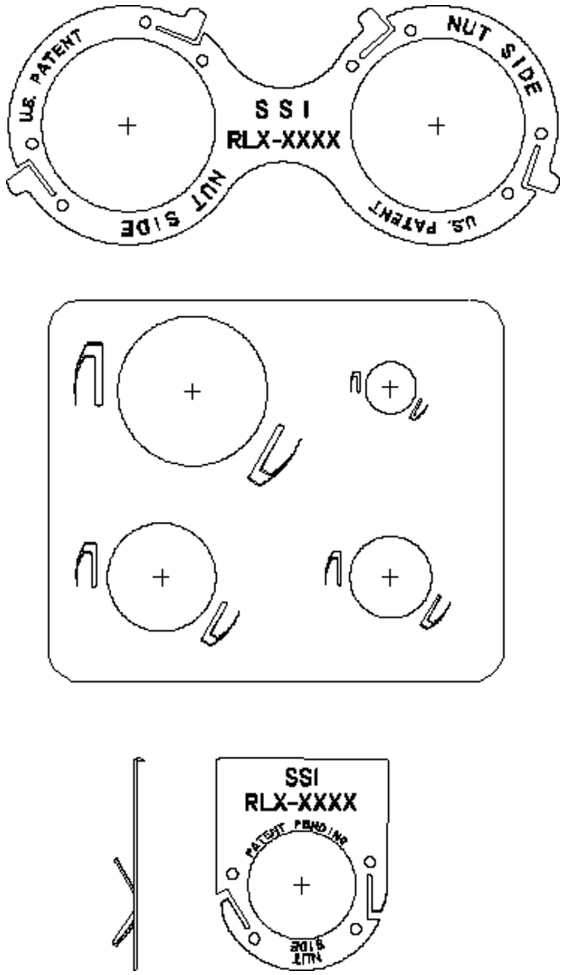


Figure 12. Alternate REALLOCK™ Configurations

SUMMARY

Quality improvement techniques such as error proofing and continuous improvement, along with innovation, have led to a new locking washer technology, REALLOCK™. This new concept provides significant advantages over safety wire and other fastener systems for a wide variety of safety related applications. In particular, these include exterior fastening of aircraft components.

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RECOMMENDATIONS

A coordinated effort among those who design, build, maintain and fly aircraft is the best way in implement continuous improvement. Fastening is one critical area that holds numerous opportunities, the pursuit of which should continue. Kresak [1] spoke from his own experience when he said “Effecting the implementation of a new fastener system required participation of specialists in many disciplines: test, process, design, stress, manufacturing research and development, equipment design, and industrial engineering.” He continued saying “Close cooperation is essential between production, purchasing quality control, fastener manufacturers, and technical specialists.”

The specialists, to whom Kresak refers, must increasingly apply the principles of quality management and continuous improvement to realize these opportunities.