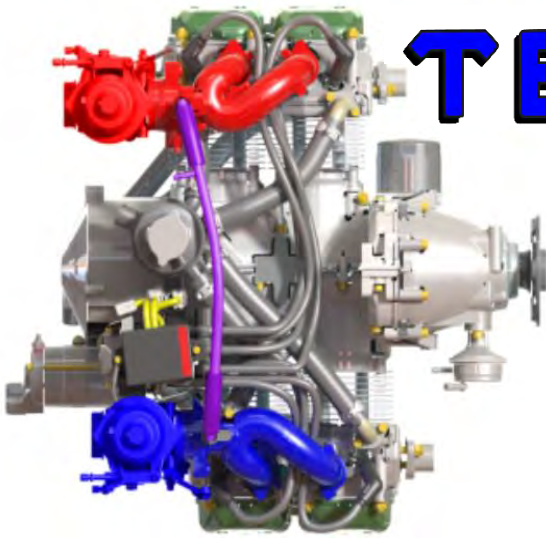

TECHNICALLY SPEAKING MAGAZINE ARTICLES

TECHNICALLY SPEAKING ARTICLES

Carol and Brian Carpenter started writing the "Technically Speaking" column for EAA's Sport Aviation / Experimenter Magazine back in May of 2015. The articles have become recognized for their focus on improving knowled and saftey in the Light Sport, Ultralight, and Sport Aircraft catagories of aircraft. The FAA recognized Brian Carpenter in 2017, in part for these contributions to the Sport Aviation community, by recognizing him as the Aviation Maintenance Technictian of the Year. Select from the most popular listings of "Technically Speaking" Articles. below.

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TECHNICALLY SPEAKING MAGAZINE ARTICLES

3-D Modeling Software "home built meets high-tech"

RAINBOW Aviation Services™

In last month's article we talked about the wide variety of opportunities available with 3-D printing. In this article, we want to talk about the process of creating those 3-D models. Within, literally, years of the initial offering of personal computers that software engineers started creating software for generating mechanical engineering drawings. And just like the computer industry itself, the exponential growth of CAD (computer-aided drafting) programs has blossomed into some of the most amazing collection of capabilities which only years ago were relegated to organizations such as NASA and Boeing. These capabilities have now become available to the average experimental aircraft builder/designer. If your aspirations revolve around being a component or aircraft designer, it is imperative that you recognize and embrace these new CAD technologies. For those holdouts, who do not wish to undergo the difficulty of learning to use a CAD program but still wish to be an aircraft designer, the only advice that we can offer is to lock yourself in the closet until you change your mind. Of course, we jest, but the capabilities of solid modeling software put the designer at such an advantage that the difficulties associated with learning the software are far outweighed by the results and capabilities that can be achieved.

There are literally hundreds of CAD programs available to choose from. The software capabilities, as well as the price, vary dramatically. Giving advice to the average person on which software to utilize is fraught with peril. Among the many considerations, price seems to be one of the most critical elements. Most of the more advanced software programs require a painful initial investment only to be followed along with an unreasonably high yearly licensing fee that continually rubs salt into the initial wound. These companies also

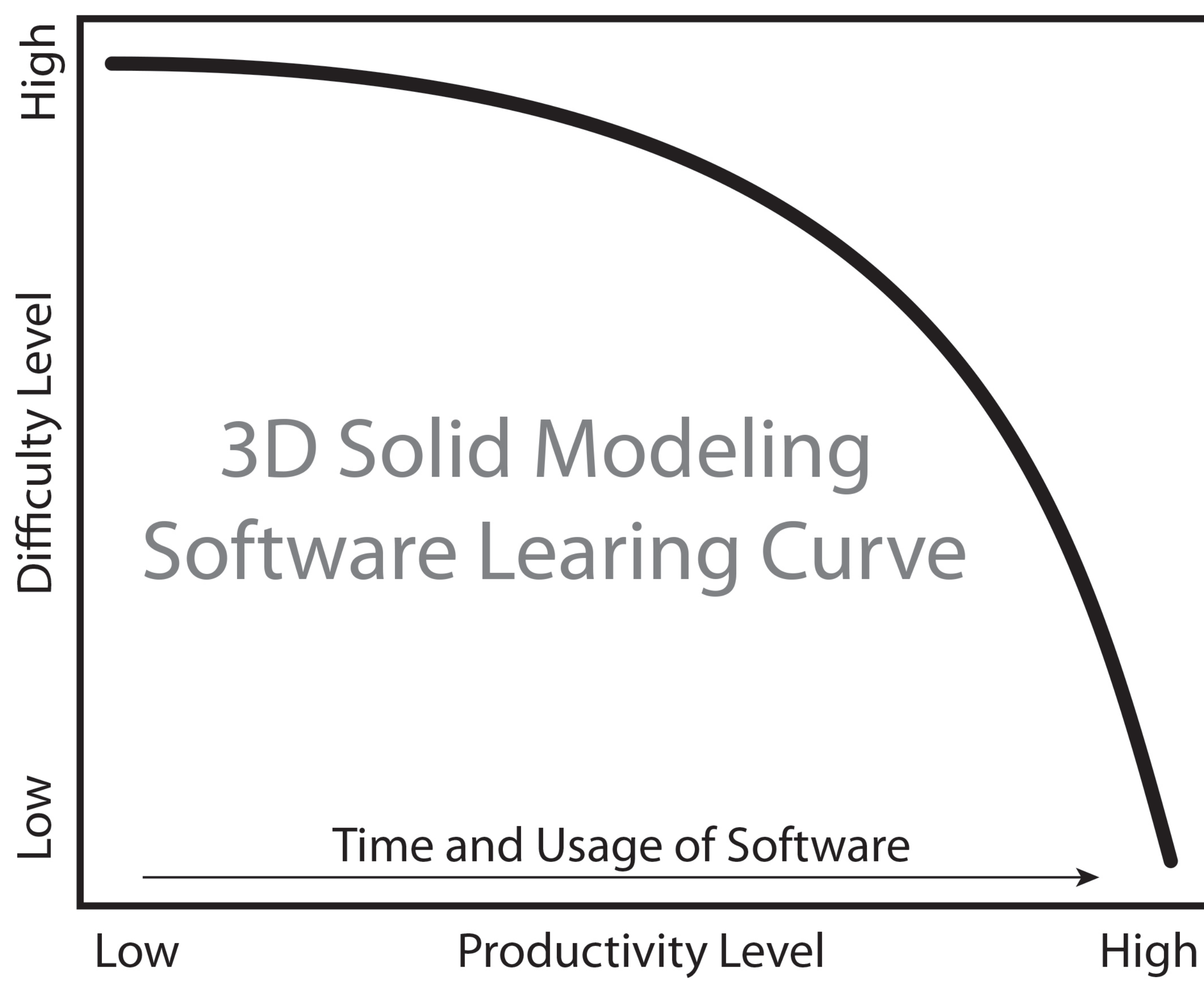

Figure: 1 3D Solid Modeling Software Learning Curve use hostage like tactics to ensure that you pay the yearly licensing fees by applying delinquent yearly fees when you try to upgrade to the current version of the software. There are also many CAD programs that can be used for free and many others that fall somewhere in the middle. It's very difficult to justify the cost of the advanced software unless you can somehow justify its usefulness. If you're new to CAD programs in general, starting off with any software will start you down the path to learning. There are cloud-based 3-D modeling programs with a great deal of capability that you can start using for free. At Rainbow Aviation, we use one of the more popular

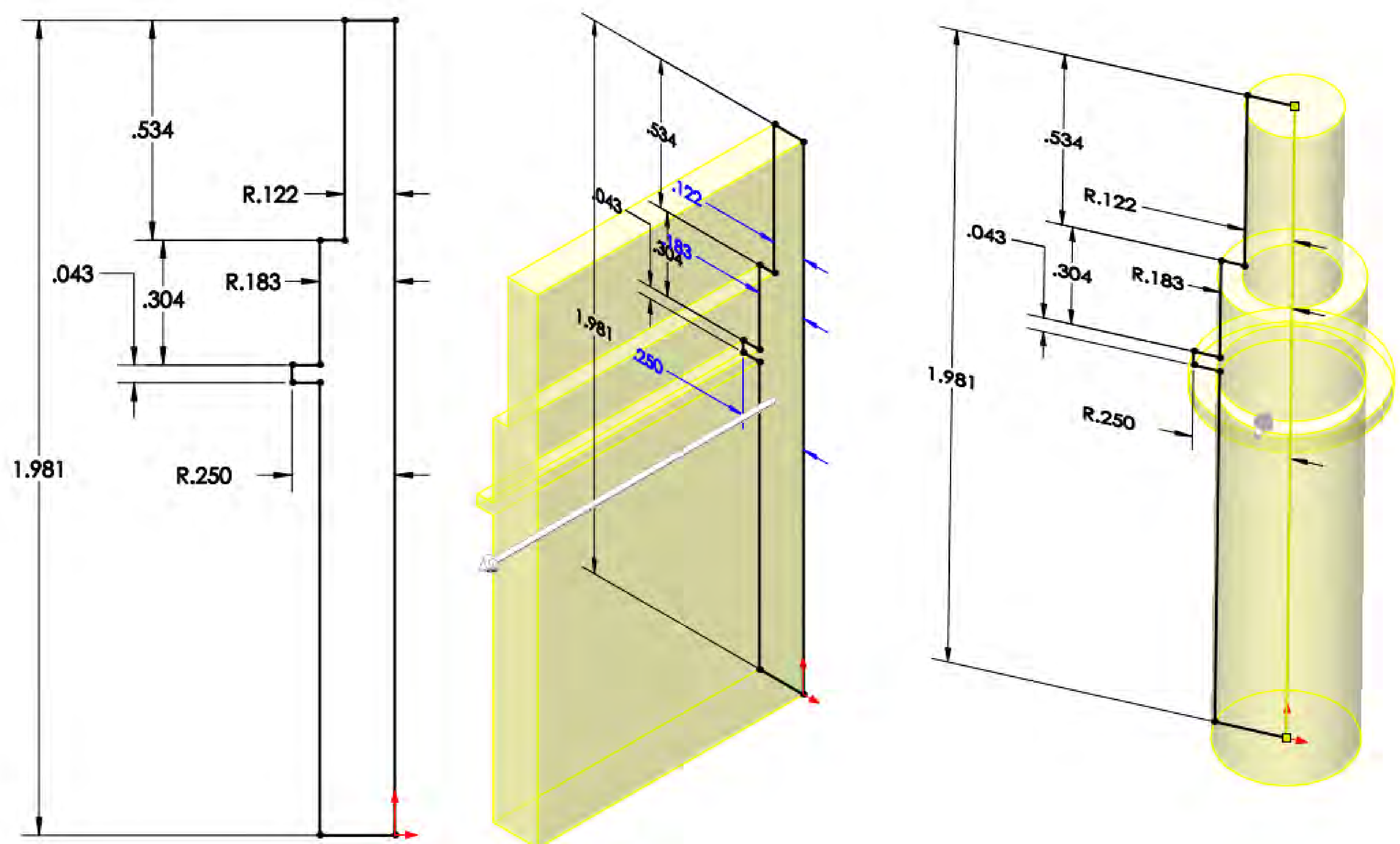

Figure: 2 Extrude and Revolve Commands

advanced software programs called Solidworks. Solidworks is one of the commercial programs with amazing capabilities with a cost structure for the basic program that is tangible (but still painful). Keep in mind that this is
the same software that is used by many major aircraft manufacturers. When you get into the more advanced capabilities and software packages from Solidworks you will need to be at the level where you are generating revenue from the software in order to justify its cost. One of our recommendations for those interested in starting to use a more advanced program like Solidworks is to start off with one of Solidworks many introductory programs. For example, taking a college extension class on Solidworks will provide you with the opportunity to buy a student version of the software at a very low cost. Although this student software does have some limitations in terms of using it commercially, it is basically unfettered software in terms of its capabilities. This provides a low-cost jumping off point which will allow you to begin the learning pro-

cess. The learning curve on a program such as Solidworks can be fairly substantial. If you've been a 2-D CAD user, you have a leg up in terms of just understanding the basic drawing principles. However, to get your brain to shift into 3-D mode can be a challenge. If you have been proficient enough to be drawing isometric views of models using depth and perspective on a 2-D CAD system, you will have to undergo a complete transformation of your thinking to transfer to a 3-D modeling software program. Once you have made the transition, you will look back upon 2-D CAD systems as a drawing method used by cavemen. This learning curve is indicative of any new technologies which you are unfamiliar with. Initially, the difficulty level can be overwhelming and the amount of productivity will be virtually stagnant. (Figure: 1) If you stick with the program, you will eventually hit the point where you can start to leverage the amazing capabilities of the software into your day-to-day usage. At this point, you will find yourself addicted to the software as if it were crack cocaine. Solidworks knows this. The more you use it, the more addictive it becomes. With the power of Solidworks at your fingertips, you figuratively become Superman. You will gladly continue to give up your lunch money if the bullies will just leave you alone on the playground with your software. As time progresses, and you become more proficient with the program, the amount of difficulty in using the software completely diminishes, and the amount of productivity increases exponentially making you a designing and creating machine.

> For those holdouts that do not wish to undergo the difficulty of learning to use a CAD program but still wish to be in aircraft designer, the only advice that we can offer is to lock yourself in the closet until you change your mind.

In conjunction with Solidworks, we use an additional program called Solid Cam which allows us to seamlessly export machine code into our CNC machines for manufacturing parts. It has literally become easier to cut a sheet of plywood in half by generating code using Solidworks/Solid Cam and our CNC router, than it is to wrestle a piece of ply-

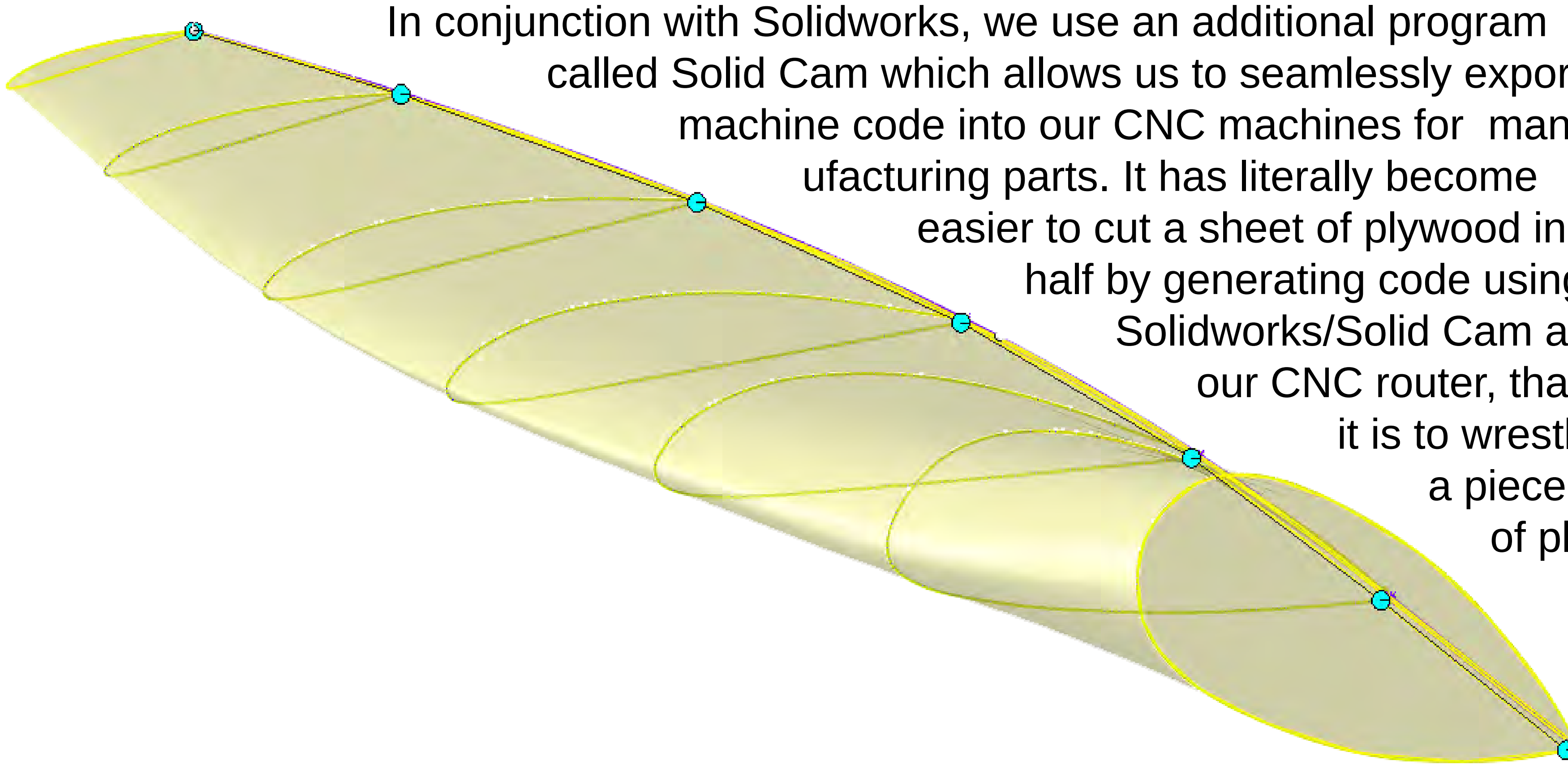

Figure: 3 Using the Loft Command to Generate a Propeller Blade

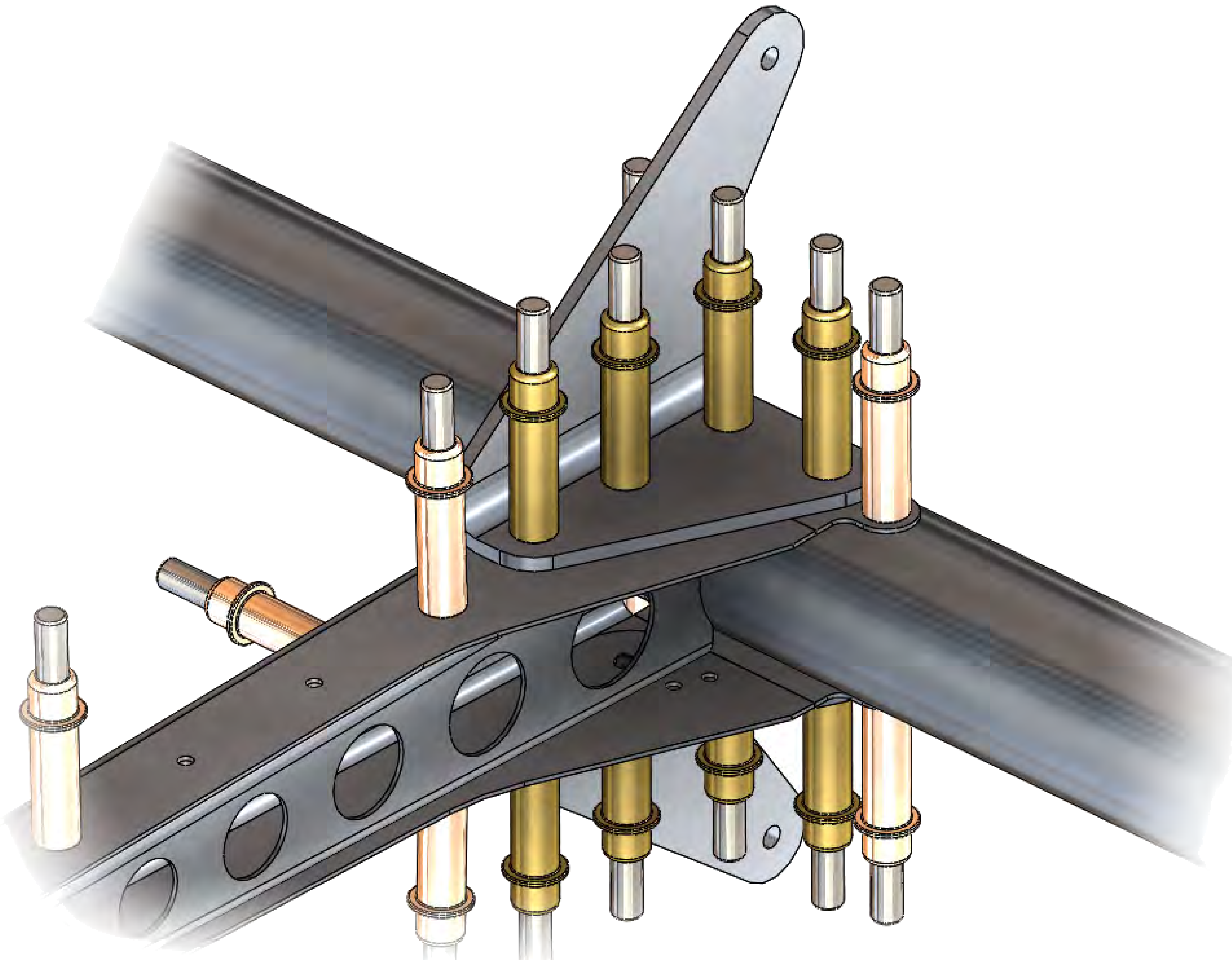

Figure: 4   *Sub Assemblies Created from Individual Parts*

wood on to the table saw to accomplish the same task. All we can say is “that’s pathetic,” but it’s true.

So let’s look at some of the basic principles around using this 3-D modeling software. Individual parts are created using simple 2-D sketches on selected planes. These 2-D sketches can then be converted to a 3-D component through a selection of basic commands like extrude and revolve. (Figure: 2) and just like the extrude and revolve commands, there are also extrude and revolve cuts. This allows us to create a 2-D geometry drawing on any face or plane and remove material from the solid part in the same fashion. You can continue to stack these types of commands, one on top of another, creating a basic part, selecting a face on that part, creating an additional 2-D sketch, and once again extruding from or cutting into your existing model. And although these are the most widely used commands which can generate a tremendous amount of 3-D modeling, there remains a host of other commands which allow us to modify and manipulate 2-D drawings into 3-D components. Other commands like “sweep” allow us to create a 2-D model along with a secondary 2-D drawing that provides a path for the extruded 2-D model to follow. This is used extensively when we are trying to create a path for fluid lines or hoses. Another command is the “loft” command. Here we use multiple 2-D drawings placed on individual “planes” and then loft them together creating a very nonlinear shape such as a propeller blade. (Figure: 3) All of these and the other commands combined together allow us to generate individual "parts." And, in the case of designing an aircraft, the sum of the aircraft is made up of sub assemblies. These sub assemblies are made up of these individual parts

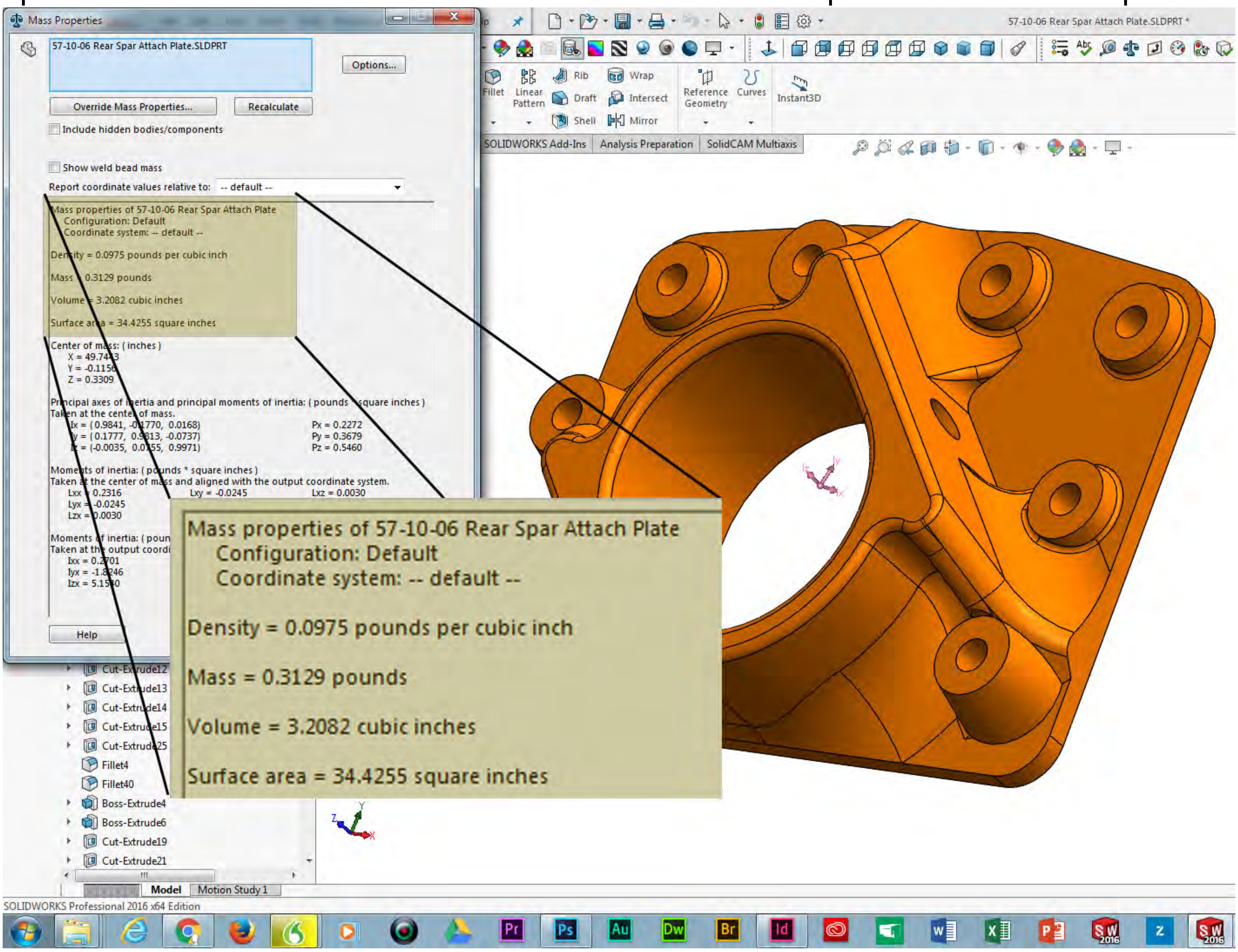

Figure: 5 Mass Properties Dialog Box

or other smaller sub assemblies. Similar to the process of building an aircraft, we take these virtual 3D parts which we have created, and assemble them into a subassembly by creating "mates" between the individual parts. (Figure: 4) It's just like building an airplane. We take our individual components and we define relationships between each one of those parts. We may tell a part that it needs to become coincident with another part, and then we may tell the holes within the parts to become concentric. We can even insert fasteners or Cleco's in the same fashion. This is helpful in generating 3-D renderings for instruction manuals. Once we have generated a single part, we can use that part over and over again within an assembly, significantly reducing the time to create a large assembly. The mating process of the individual components has nearly limitless possibilities. In addition to basic mating commands like coincident, tangent, parallel, collinear, concentric, there are also advanced commands which allow a part to be positioned while allowing the individual part to move through specified parameters. Perhaps you have flight controls that move in the 3-D model. These control surfaces can have their deflections limited in the 3D assembly to provide a more realistic representation of actual conditions that act on the aircraft. If you can visualize a component on an aircraft, and how it relates to the rest of the structure, you can represent that interaction in a virtual environment using the Solidworks software.

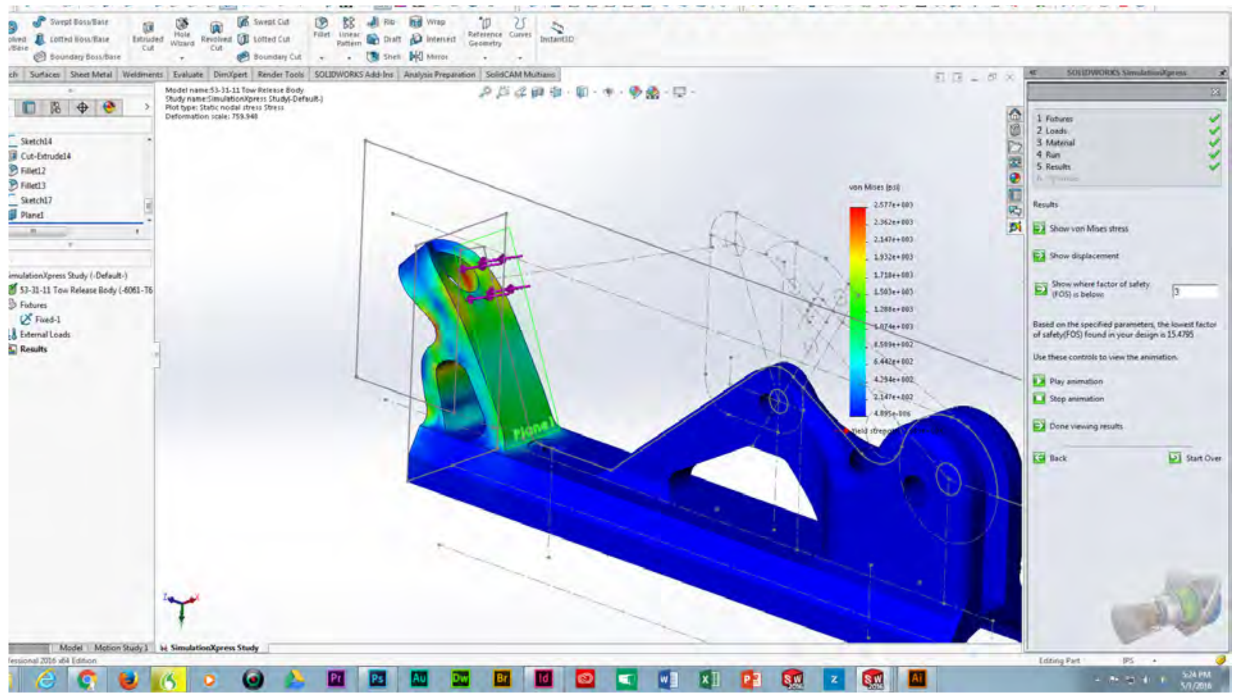

Figure: 6 *"Simulation Express" Stress Analysis.*

One of the most useful features within solid works, for us aircraft designers, is the "mass properties dialog box." During the creation of a part, we can assign material properties to the part. This will allow us to pull up the mass properties dialog box and obtain information about the weight of the part as well as other useful information. The dialog box will also create a triad arrow showing the center of gravity on the individual part. When we assemble these parts into and assembly, the software will calculate the combined weight of all of the individual parts, as well as the center of gravity of each part, to generate a center of gravity for the completed assembly. We use the surface area function on a regular basis to calculate the amount of time that a part will have to stay in the anodizing booth at a given voltage.

Also contained within the basic entry-level version of solid works is the ability to use what is called simulation express. (Figure: 6) This is basically a finite element analysis (stress analysis) program that allows us to simulate the material reactions to simple loads applied to a single component. More advanced capabilities, which allow the analysis of complete assemblies, are available for upgraded versions of the software.

And even the professional level software, which we use, allows for the creation of some amazing realistic photo renderings using the render tools add-in module. In our office, in hangar 7 at the Corning Municipal Airport, we have a myriad of rendered photos of the EMG-6 electric motor glider posted on the bulletin board. I'm constantly surprised by the number of people who think that these renderings, created in solid works, are actual photographs of the aircraft. (Figure: 7)

One of the greatest advantages of working in a 3-D modeling software program, such as Solidworks, is it allows you to build your design "virtually" before you cut your first piece of material. This allows you to check the interaction of individual components, check for clearances, get a visual representation of the aesthetics of a assem-

Figure: 7 Photo Realistic Rendering of the EMG-6 Electric Motor Glider

bly, check the weights of components along with the weight of the total assembly, and even check center of gravity.

If you are the inventor/creator type, you should put away any apprehension you may have about approaching 3-D modeling software. This is the future. You just need to get started. If you have a restricted budget, we recommend that you start off with some budget software. Much of the software out there will do the majority of what you need to do in designing your own aircraft or component. Transitioning from one 3-D modeling program to another is much easier than starting from scratch. Even if you want to jump in with both feet and start working with something like Solidworks, do your homework. Check the compatibility of your computer with the requirements of the software you are considering. Our Dell T5500 desktop computer with an 8 core processor and a $2000 video card finds itself challenged on a regular basis. Creating a 5 minute HD video at 30 frames per second with each frame fully rendered often takes as much is 60 hours of computing time. The results are spectacular and the computational gymnastics, which the Solidworks software is capable of, is nothing short of amazing. The use of 3-D solid modeling software is quickly becoming the norm rather than the exception, especially when dealing with experimental aircraft. We encourage you to embrace the technology and begin the learning process. The rewards are beyond imagination.

Carol and Brian Carpenter are owners of Rainbow Aviation Services in Corning, California. For more Information visit www.rainbowaviation.com

There has been a significant amount of advancement and usage of the LPD (layer plastic deposition) 3D printers in the experimental aircraft world in recent years. The cost of single component prototyping has found a really important niche for these low-volume applications in experimental aircraft. We have been using ABS plastic 3D printed parts in literally hundreds of dif-

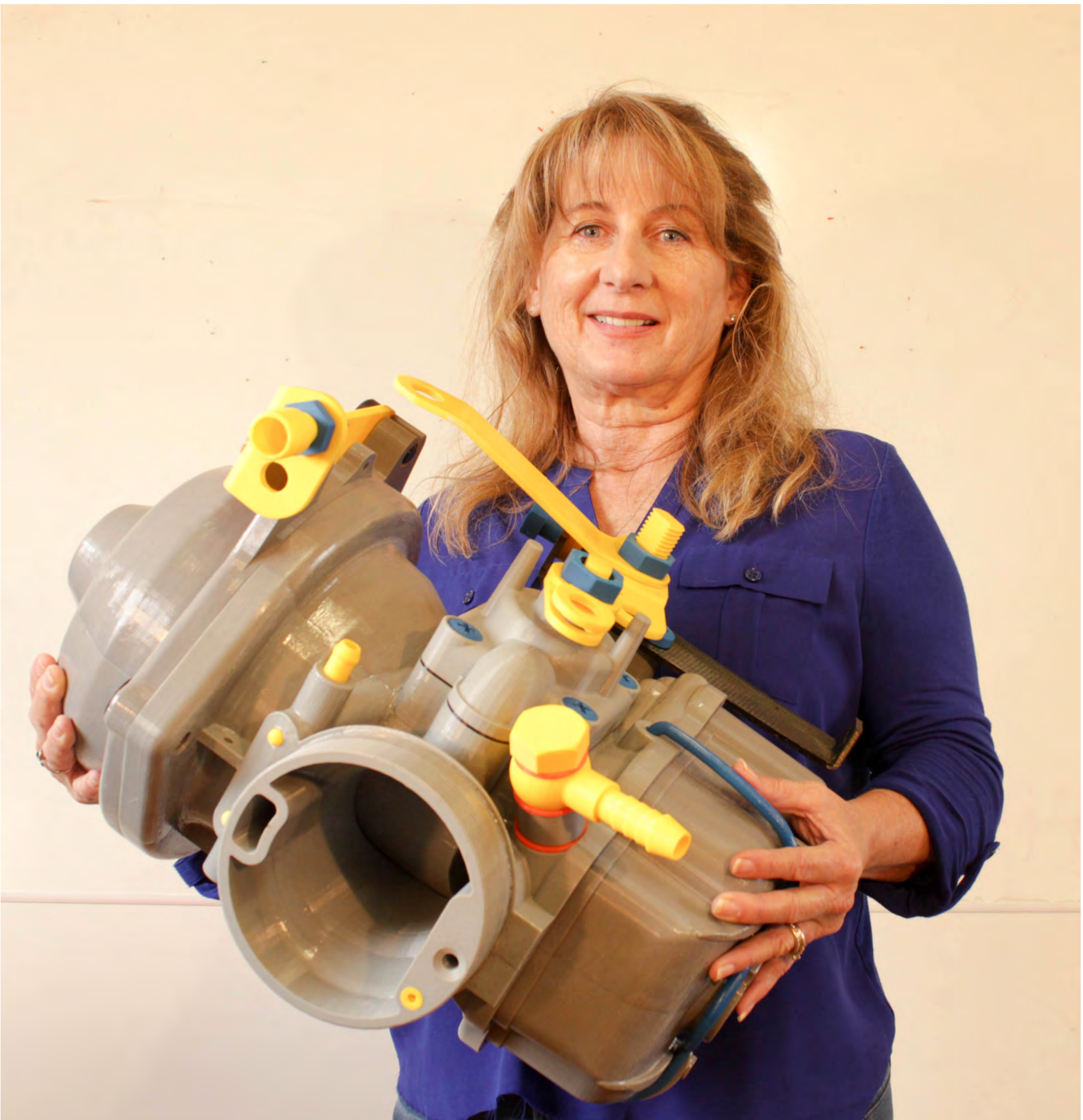

Figure: 1 300% Scale Bing Carburetor

ferent locations on different aircraft and expect to see an even greater usage in the future. Although the focus of this 3D printing technology has been on the aircraft side, we want to back up a bit and take a look at what we believe to be an even more significant utilization of the 3D printing technology: 3D printing for the small workshop. It isn't until you spend a significant amount of time building components on a 3D printer

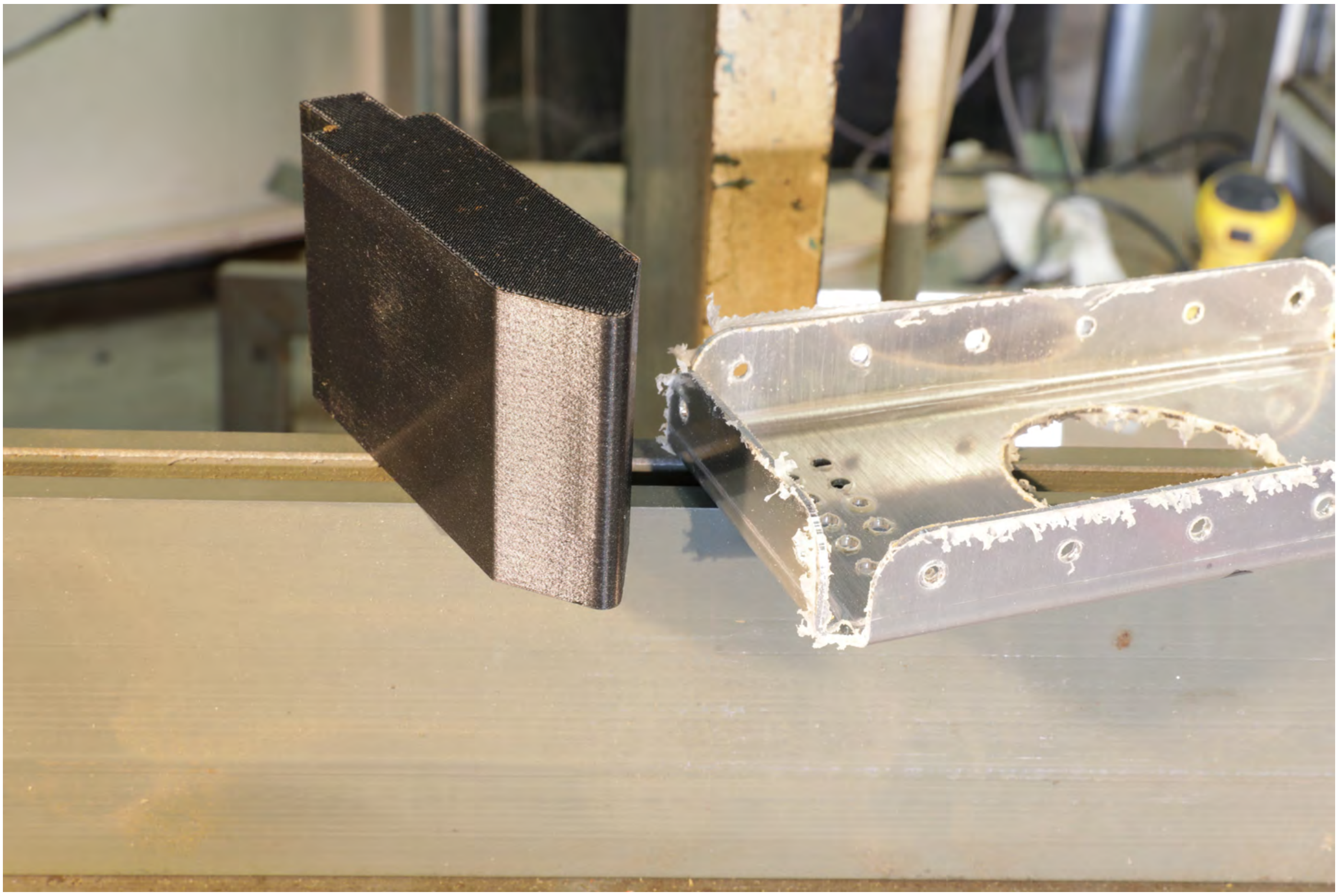

Figure: 2 *3D Printed CNC Press Brake Die*

that you start to realize its real potential. In recent years, we have started to use the 3D printer for building a whole series of one-off tools designed for very specific tasks. The more that we use the technology, the more aware we become of its potential. In this article, we will explore some of our more successful and useful applications.

One of our bigger projects was the 3D modeling of a 300% scale Bing carburetor used on the Rotax 912 series engine. (Figure: 1) In our Light Sport Repairman Maintenance classes, that we teach, we have found that having a giant scale carburetor modeled in precise detail to the exact dimensions of the real carburetor, allows the students (especially the one sitting in the back of the classroom) to get a better view of the individual components. Every single component within the carburetor is individually 3D printed and then assembled just as we would assemble the real carburetor, only in giant scale. This allows us to take apart the carburetor piece by piece with much better visual comprehension during the process. Once we have 3D modeled the individual components as well as the entire carburetor assembly, we now have the ability to section out portions of the carburetor and 3D print cut-aways so that we can visually see the internal fuel and air passageways. Although we doubt we will 3D model the entire Rotax 912 engine, we are currently 3D modeling many other components like the starter sprag clutch, gearbox, and fuel pump. We find that students respond very well to the utilization of these large visual aids. This one-off modeling of these type of specialty items can only be cost-effective with the utilization of the 3D printer.

Another very successful experiment that we have undertaken has been using 3D printed press brake dies for bending aluminum sheet metal. This started off by the necessity to bend a very short segment of aluminum on our CNC press brake. Although we ordered a press brake die the shipping time was interfering with our ability

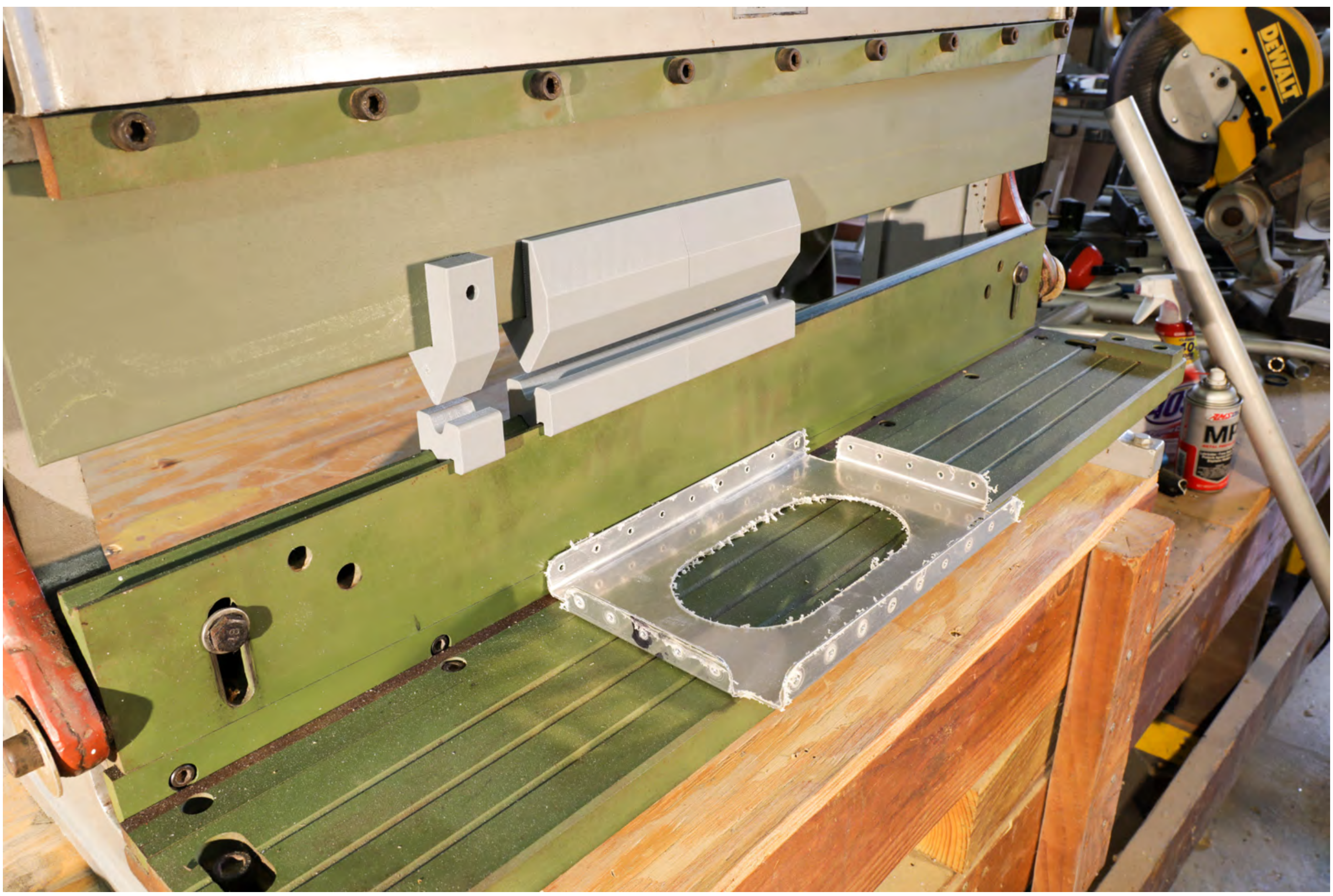

Figure: 3 *Press Brake Dies For Harbor Freight Retrofit*

to proceed with the current process. On a whim, we decided to see what we could do with a 3D printed press brake die of the exact dimension needed for our task. We selected a 3D printing medium called Z-UTRAT. This is a proprietary blend based on ABS plastic sold specifically for our Zortrax M 200 3D printer. This plastic has superior hardness and impact strength making it ideal for the task of making a press brake die. The intent was to make a 3D printed die that would last for a few applications so that we can get on with the process of bending this one particular flange. Even if

Figure: 4 *3D Printed Prop Balancing Insert*

the 3D printed die didn't last very long, we felt that would be an acceptable cost to allow us to get on with the project. After bending over 200 bends on the flanges on the .040" thick 2024 T-3 aluminum bulkheads, we were surprised to see that there was no visible wear occurring on the 3D printed die. (Figure: 2) Not only was the die holding up exceptionally well, we found that the marring that would normally occur with the steel dies was nonexistent leaving the aluminum part in better condition than if we had used the conventional press brake dies. Now, we're sure that if improperly used, or if the aluminum becomes maladjusted during the bending process, you can see how the plastic would probably take a beating. Our plan for the long-term usage of the plastic bending dies is to use JB Weld epoxy to repair small nicks for wear on the surfaces of the plastic dies. So far, no repairs have been necessary. This led us to our next experiment more appropriate to the experimental homebuilder. We have an old harbor freight combination shear, press brake and slip roll that we never found very useful for bending aluminum. This is primarily because the press brake dies that come with the tool have a 90° sharp edge, making it virtually unusable for bending aluminum. Aluminum needs a minimum bending radius in order to prevent cracking of the aluminum during the bending process. After having succeeded in using this system with the 20-ton hydraulic CNC press brake, we felt confident that we could resurrect the old harbor freight press using the same type of 3D printed dies. If this worked, this would now make the tool useful for bending aircraft aluminum. We created 3D printed male dies to slide onto a 1/4-inch piece of mild steel in place of the original male dies, and designed a new female die to fit over the top of the existing tooling. After much experimentation, we were convinced that this will lend new life to this low-cost piece of equipment. (Figure: 4) This previously inadequate tool now has some real potential for many budget minded aircraft builders.

Another one of our more recent successes, was to build a specialty prop balancing tool. We had a propeller that needed balancing and although we have a total of four

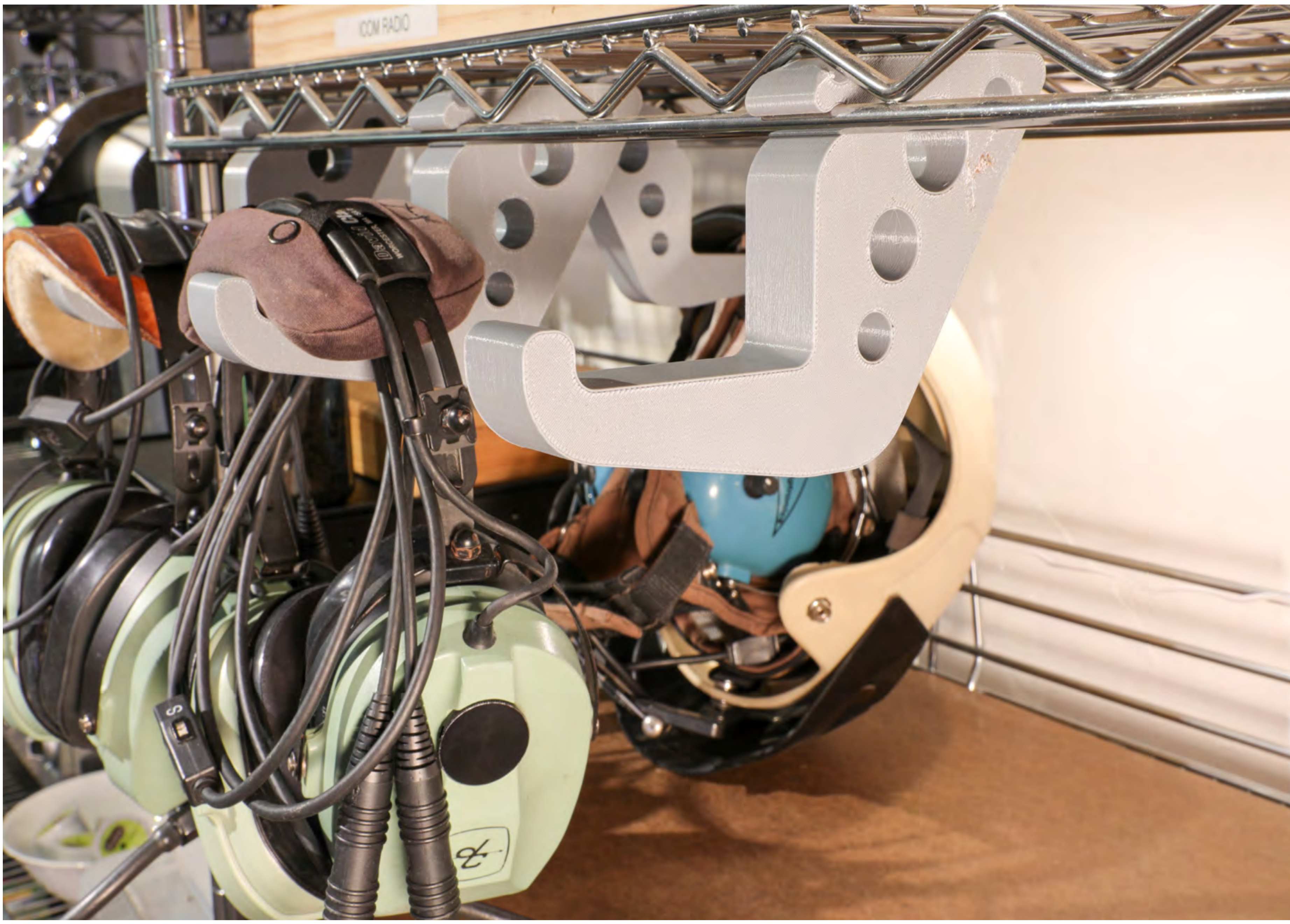

Figure: 5   *Headset Hooks*

static prop balancers in our shop, none would work for this particular propeller. After a half hour of design work with Solidworks, we were able to design and start printing a new prop balancing tool insert specific to this prop. Using the existing components from another prop balancer allowed us to create an insert with a very tight precision fit and accurate centering cone specifically for this application. The total printing time was only about four hours and, by the time the afternoon had rolled around, we had a prop balancer that work perfectly allowing us to complete the job in a much more expeditious time frame than what would have otherwise been possible. And the best part of the whole process was that the total cost for materials was less than $10.

We also have been using the 3D printer to make individual specialty tools like positioning fixtures for the drill press. Creating “V” blocks for drilling tubing as well as round tube marking tools allowing us to create reference marks around a tube. We are constantly developing small add-on items for our milling machine. Tool and work holding fixtures and coolant containment devices. The ABS type plastics stand-up very well to the oil and coolant environment. We are constantly making specialty camera mounting devices for different aircraft applications. And even in the office the applications seem to be never ending. We recently got tired of untangling all the cords from the shelf full of aircraft headsets and decided to create some specialty hooks that will adapt to our Costco shelving system. (Figure: 5) The ability to be able to make specialty tools or even do-dads on a one-off basis can really allow your creativity to flourish. We use the 3D printer on a daily basis and over the last couple of years we have probably printed several thousand parts and components. The general reasoning for purchasing any new piece of equipment or tool is the justification that it will save you time and money. Although we originally purchased our 3D printer without a clear indication of the cost benefit analysis, it soon showed itself to be an indispensable part of the workshop. Many believe that within a few short years the 3D printer will be as commonplace as the ink-jet printer is today. The work flow and utilization of the 3D printer coupled with the ability to 3D model in SOLIDWORKS has become so seamless and easy, that we can’t imagine living without its capabilities.

We are on the cusp of a new era in experimental aviation like we have never seen before. We often hear doom and gloom from those who have been in the general aviation market and who have seen the downturn in the number of active pilots and airplanes coming off the factory floor. The overused cliché “it’s always darkest just before the dawn” is really apropos in this circumstance. We are here to tell you that the future of aviation looks very bright. There are several paradigm shifting technologies that are changing the world of aviation equivalent to that the Wright brothers first flight, the dawn of the jet age, and Burt Rutan’s contributions to composite aircraft. Some of the most exciting of these new technologies which we have embraced, include, electric propulsion, 3-D solid modeling software, and 3-D printing. Over the next couple of months, we will be writing articles exploring, in-depth, some of these new technologies which are rapidly becoming tangible for the average aircraft builder. In this article, we’re going to take a closer look at the possibilities of using 3-D printing in experimental aircraft.

With today’s proliferation of 3-D solid modeling software available to the average experimental aircraft builder, we are now starting to see the leveraging of this

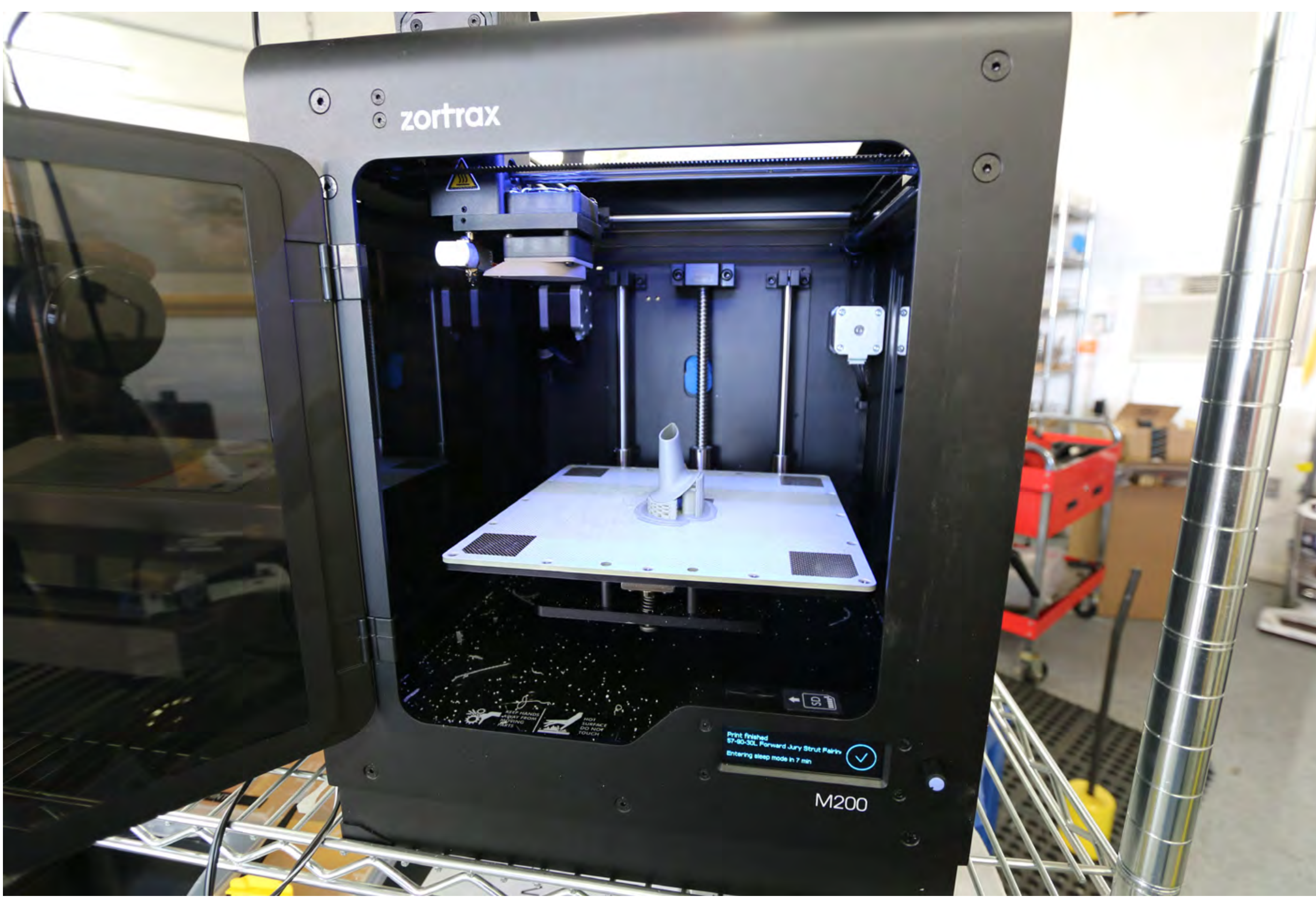

Figure: 1 Zotrax M200 Pro 3D Printer

technology into the average builder's toolbox. We have been using 3-D modeling software for the past 30 years, and "Solidworks" extensively for the last 15 years. We have become so dependent upon it, that we feel it is one of the most valuable tools that we use on a daily basis. With the ability to 3-D model components virtually on your desktop, the cost of design has plummeted dramatically. It allows us to import the 3-D models into other software and export g-code (computer numerical control (CNC) programming language) for manufacturing of components on different CNC machinery. Seeing this potential, we purchased our first CNC machine some 15 years ago. Since then, we have continued to exploit the advantages of this technology and we now operate 6 different CNC machines. The latest of these "machines" if you can call it that, is a 3-D printer.

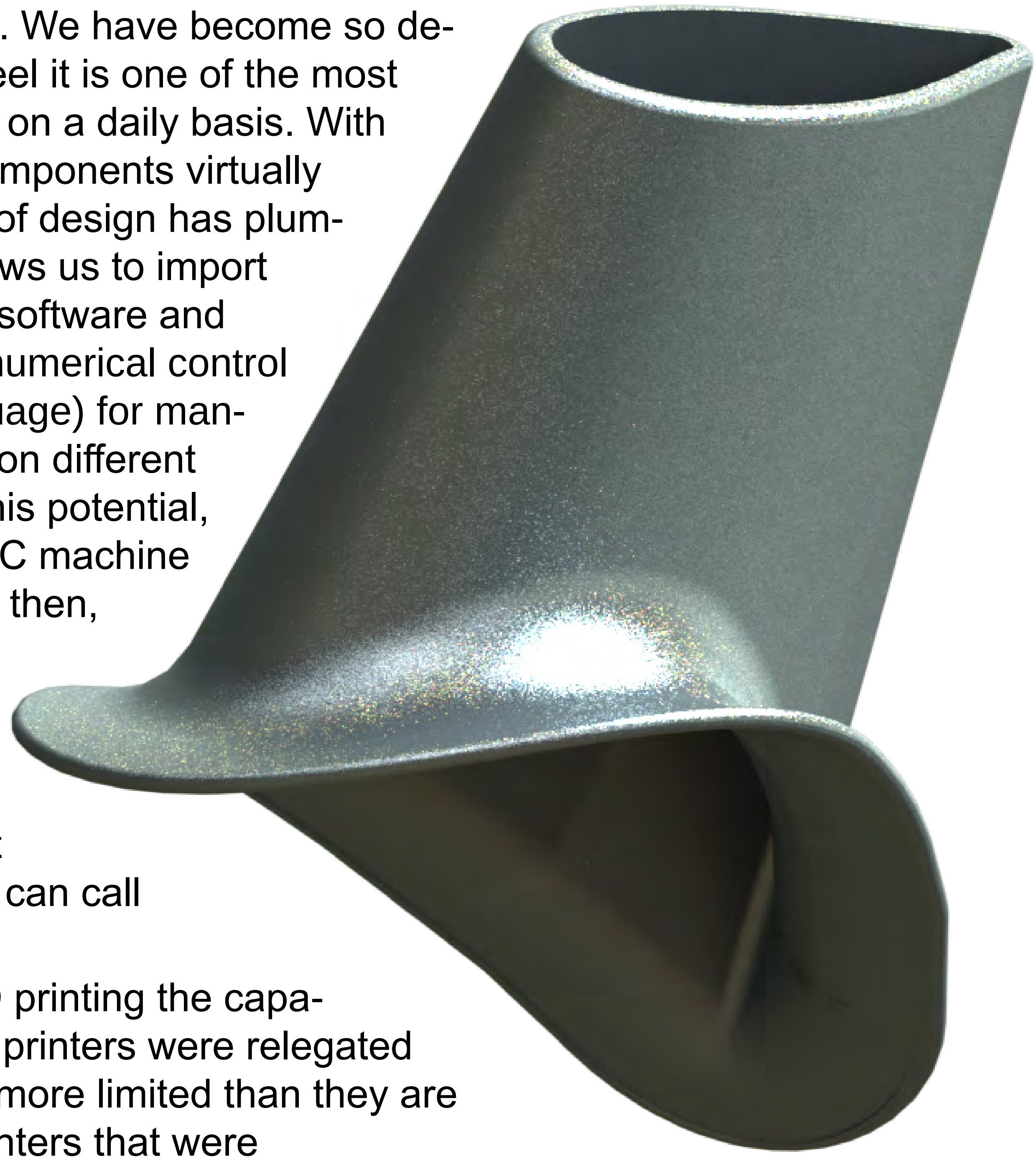

Figure: 2 3D Modeled Jury Strut Fairing

In the early days of 3-D printing the capabilities of the low-cost 3-D printers were relegated to the hobbyist and much more limited than they are today. Many of the 3-D printers that were capable of building parts for aircraft quality applications were just too expensive. These were hard to justify even for many small aircraft manufacturers, let alone the average experimental aircraft builder. And the quality and capability of the hobby printers just didn't meet up to expectations. However, the exponential growth in the 3-D printing market has significantly closed the gap between the hobbyists type 3-D printer and the high-end manufacturing 3-D printers. Over the last year or so, we started to see more and more 3-D printers with high enough quality and low enough pricing that the temptation to purchase became overwhelming. One of the tricks that Brian uses to justify the purchase of a new piece of equipment, when in fact it doesn't really make sense from a business standpoint, is to throw it into the category of a birthday present. The possibility of using the 3-D printer for this article, combined with the birthday present fuzzy math, and the obvious inevitability of needing a 3-D printer to compete in the current business environment, finally met the threshold to justify the purchase of a 3-D printer for "work".

Having closely followed the 3-D printing evolution for the last several years, when it came time to purchase, we already had a pretty good idea of which 3-D printer we wanted. We elected to purchase the Zortrax M-200 Pro 3-D printer. (Figure: 1) Similar to purchasing an aircraft, there are a lot of different criteria which goes into the decision-making process for any piece of equipment. Being able to produce end-use products of aircraft quality was first on the list. The price point had to be reasonable enough to see the possibility of the machine paying for itself over time.

There are many different types of 3-D printers. The Zortrax M 200 is called an FDM (Fused Deposition Modeling) or LPD (Layered Plastic Deposition) printer. This is a process of fusing together layers of melted plastic. The FDM printers are the most popular printers in the under $2000 price range. The 3-D printing process is really quite simple. Like most CNC machines, the printer uses drive motors in the X, and Y, axes to drive the print-head and another drive motor to control the build platform in the Z axis. It also uses a 4th axis drive motor to control the feed of the plastic into the heated print-head. The plastic print media on the Zortrax M 200 is .069 inch diameter plastic rod and comes on coiled spools. The plastic media is fed into the drive gears on the print-head which controls the feed rate into the heated extruder. The heated extruder is simply a small reservoir in the print-head which can be heated to over 700°F. This melts the incoming plastic media prior to being forced through an extruder nozzle. After the .069 inch plastic media is forced through the extruding nozzle and exits as a .015 inch diameter bead. This bead of melted plastic is now applied to the model on the heated build plate in z-axis resolutions as fine as .0035 inch layers. This allows this new generation of 3-D FDM printers to produce extremely high resolution components.

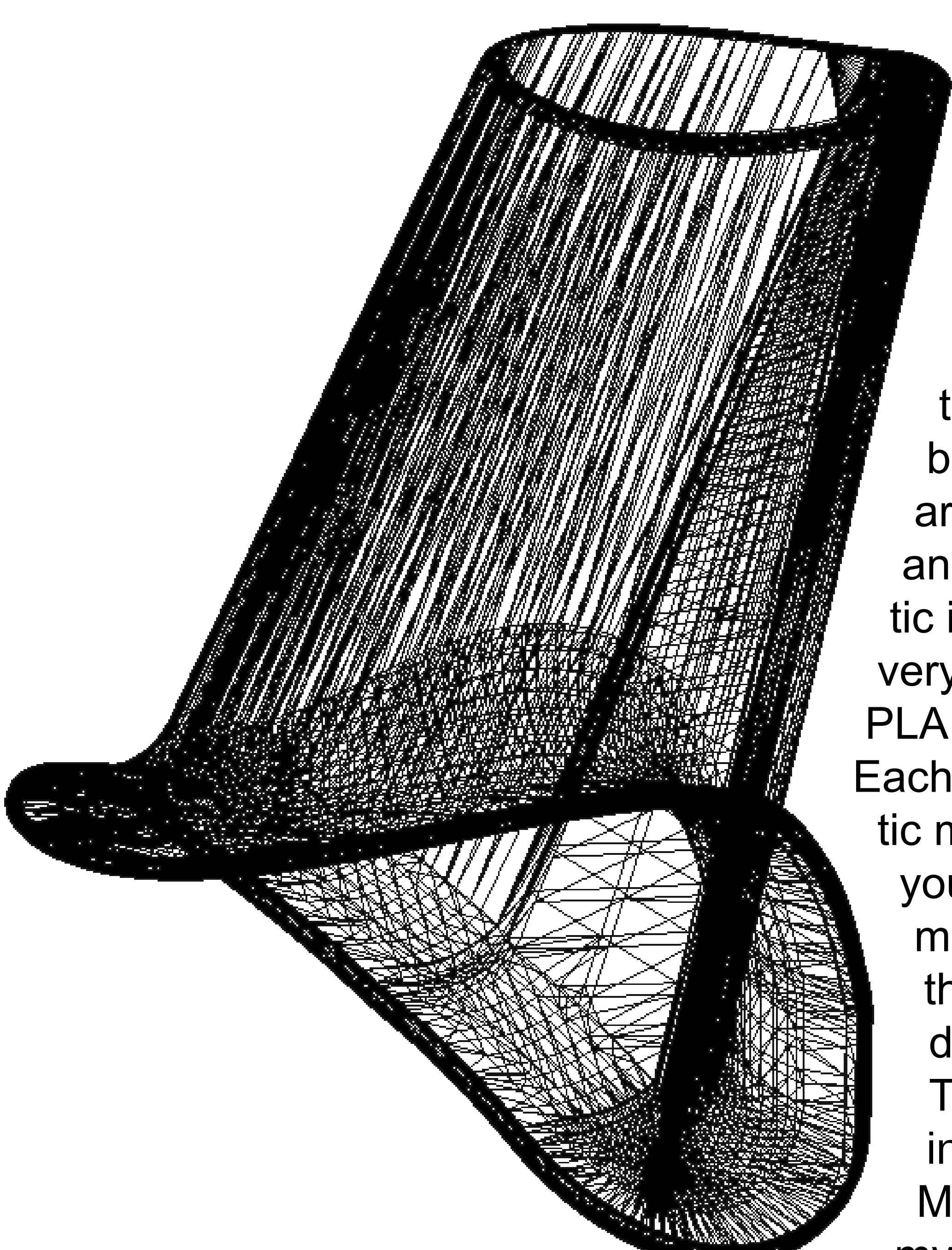

Figure: 3 .STL File Format

The selection of materials used in these type of printers is growing on a daily basis. The most popular types of material are ABS (acrylonitrile butadiene styrene) , and PLA (polylactic acid) plastics. ABS plastic is very useful for end use products and is very cost-effective at about $30 per roll. The PLA and other plastics run about $50 per roll. Each roll contains about 1.75 pounds of plastic material. It’s surprising how many parts you can make from a single role of plastic material. The Zortrax M 200 currently has the option for 5 different types of plastic depending on your printing requirements. The company is also currently developing several other exotic media for printing. Many other printer manufacturers have a myriad of printing media including carbon fiber and Kevlar reinforced plastics for high-strength applications. Silicone and rubber media, wood look-alike materials, simulated metals, and the list goes on. Some of the more interesting applications involve using a metal conducting material to print 3-D electronic circuit boards. And, of course we've all seen the news headlines, doctors using living cells to 3-D print functional organs for transplant into the human body.

Let's look at the sequence of events taking place in the process of making a useful 3-D printed part for your aircraft. The first process in creating a 3-D printing part is to create your part in a 3-D modeling software program. (Figure: 2) 3-D modeling software has been around for many years and is now available in many different formats from relatively basic software which can be used for free, to sophisticated modeling programs like Solid Works which can cost several thousands of dollars per year to maintain your subscription. Keep in mind though, even if you are not a 3-D modeling expert there are literally hundreds of thousands of 3-D models available for free download online. For example, we provide all of the 3-D printed part STL (Stereo-lithography) files for the EMG-6 Electric Motor Glider on our website for free.

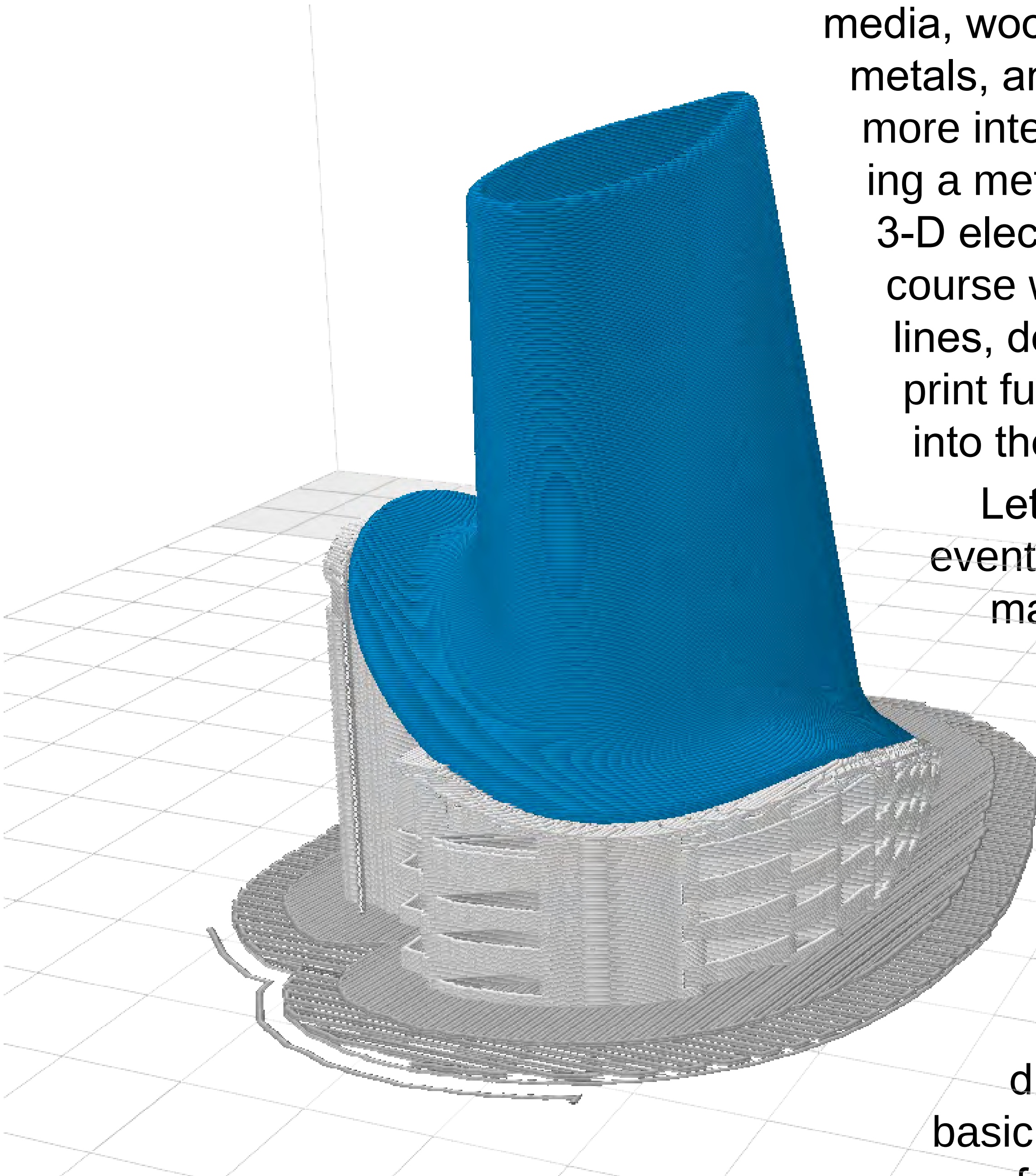

Figure: 4 Z-Suite 3D Printing Software

After you have created your 3-D model, you will need to export the file into and STL file format. Unlike standard CAD file formats, the STL file describes only the surface geometry of a three-dimensional object through triangulated surfaces. These are created using the cartesian coordinate system. Every point of each of the triangles uses an X, Y, and Z coordinate to define their location. Most CAD programs, including the free programs, have the ability to export into the STL file format. (Figure: 3). Next drag-and-drop, lit-

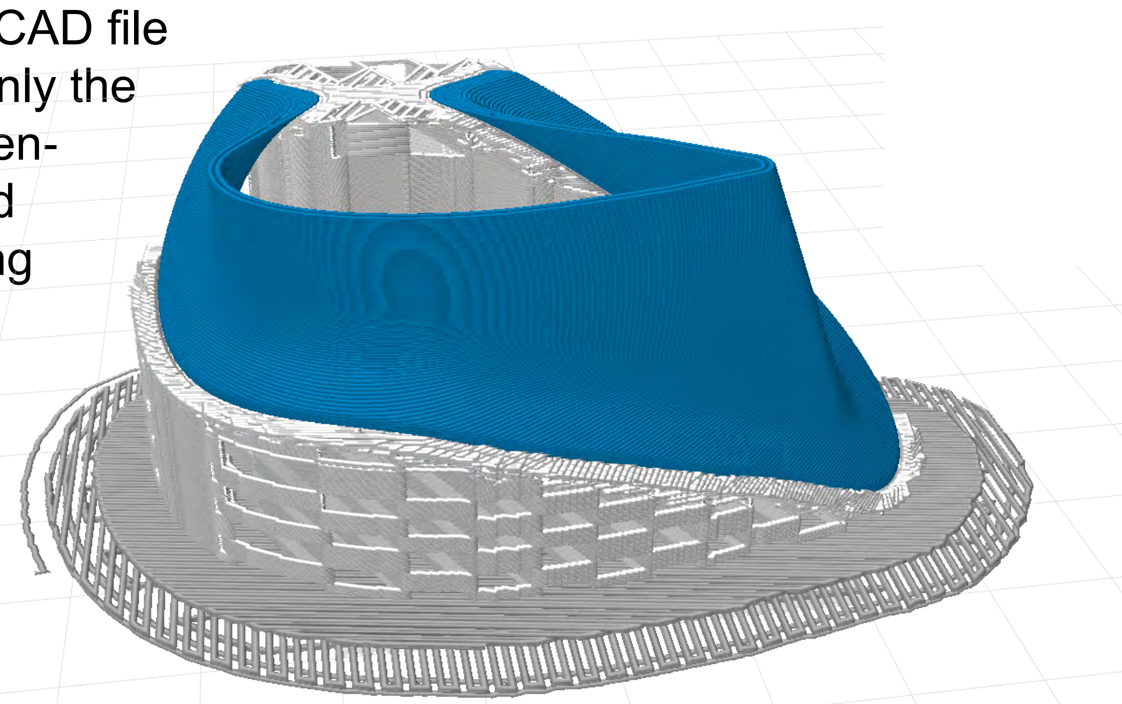

Figure: 5 Visualizing the 3D Model Layers

Figure: 6 Separating the model from the support structure

erally, the STL file into the Z-Suite software that comes with the Zortrax printer. Working with the software default parameters allows a beginner to press the “print” button and the software creates a raft, support structure, and part layout automatically. (Figure: 4). The Z-suite software is basically a slicing program that converts the STL file into individual layers that will be printed. Within the software, you can scroll through the individual layers to see how the part will be constructed one layer at a time. (Figure: 5) When you are satisfied that your part will print in the orientation that you wish, simply press the “Save To Print” button and save the file on an SD (Secure Digital) memory card. This file contains the “G code” necessary to run the 3-D printer. This is the equivalent of a post processor file and is specific to each type of printer. In the case of the Zortrax printer the file extension is a “.Z-code” file. You can now transfer the data from the SD card to the printer using a simple single button menu-driven interface. Select “model”, select “filename”, and press enter. At this point you can simply walk away from the machine and leave it to its own devices. One of the characteristics of a 3-D printer is that they are relatively slow. A simple part like, the jury strut fairing, which we are using in this article as our example, can take up to 2 hours to print.

The machine will heat the build platform to a maximum temperature of 230°F. and it will then preheat the extruder upwards of 700°F before the printing will begin. Starting with the machine in the cold configuration this can take up to 15 minutes before the printing process begins. The Z-suite software also provides you with information about the length of time required to print the part as well as how much material will be used and the total weight of the completed part, raft, and support material. For this small jury strut fairing, which we are using for an example, we will expect the part to take 1 hour and 49 minutes to complete. We will use 4.58 meters of Z-Ultrat plastic. And the final weight will be 11 grams. If you happen to be in the vicinity of the 3-D printer when it finishes, the printer will give a beep indicating that the process is finished. If you rush in to extract your part from the build platform, you will find that the platform is very hot. Extracting the part from the build platform initially seems rather difficult, but once you've developed the technique using a scraper, you soon find it to be a rather painless process. After extracting the part from the build platform, you are left with your part which is still attached to the support structure and the raft. The software designs a raft, which is a platform from the same plastic material as your part is manufactured from. The raft plastic is extruded into the holes located on the heated build a platform. This builds a rigid structure which adheres exceptionally well to the build platform during the printing process. This raft and support structure material is designed and printed in such a fashion that it very lightly attaches itself to the final product. With a few simple tools you can separate the part away from the raft and support structure. (Figure: 6) Many of the plastic materials are UV resistant and can be placed directly into service without any other processing. The quality of the parts are really quite amazing in their off-the-printer configuration. (Figure: 7). However, if you're still not satisfied with the finish quality of the final part, there are many post processing procedures that can be employed to improve the surface finish. We use acetone with many of the plastics to repair cracks or glue pieces together. Acetone can also be used to melt the surface and provide for a more contiguous and smooth surface. The parts can be sanded very easily making them as smooth as any composite part, and many of the plastics are very compatible with painting. Prior to 3-D printers the possibility of making a part like this would be out of the realm of practicality. The cost to develop a mold and produce a plastic injection molded part would require that you

Figure: 7 The 3-D Printed Fairing On the EMG-6 Electric Motor Glider produce thousands of parts to even make it worthwhile. With 3-D printing we can design and produce as many prototypes as needed to finally perfect the part, as well as produce functional parts on an on-demand basis. The Z-suite software even contains a cost calculation function as well. Plug in the price per roll of the material that you're using and the software will tell you the exact cost for the material. By the way, the jury strut fairing that we have used for our example only used $.62 of material. This simply changes everything. The lightweight nature of plastics lend themselves very well to aircraft components. There are many other advantages that we've not been able to leverage until now. The ability to build a lattice or honeycomb structure inside of an existing part would be a highly complex process. With 3-D printing, we can simply program a lattice structure into the part to both save weight as well as significantly influenced the structural characteristics. (Figure: 8). The possibilities for 3-D printing in experimental aircraft is almost unimaginable at this point. We are sure to be amazed at the new ideas and products that will be developed by the talented individuals within the EAA community in the next couple of years. At the time of this article, we are brainstorming the best method to provide a file sharing site for all of the EAA members to share their 3-D modeling files for 3-D printing.

Figure: 8 Lattice Structure Printed Inside of an Enclosed Shell

3-D printing has become so prolific that there are an unlimited number of companies that will offer 3-D printing services, so you can take advantage of the 3-D printing revolution without having to purchase your own printer. Many businesses like Staples and the UPS store now offer 3-D printing services. Or, possibly, a group of aircraft builders might pool their resources to purchase a 3-D printer for joint use.

Looking to the future, we can see that a 3-D printer will be as commonplace as the desktop printer in your home office. Capt. Kirk would probably be annoyed at the slow speed of printing, but the reality is, the Star Trek replicator exists today.

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We are often reminded, by students attending our maintenance classes, just how confusing hardware identification can be. After 40 years in the business and dealing with hardware on a daily basis, we often take for granted all of that seemingly generic information that was, at one point, a mystery to all of us as well. Handing a student a 200 page manual with literally thousands of different types of nuts and bolts that are rarely used, doesn't really help the situation. In reality, the average home built aircraft uses a small selection of different hardware that is universal to the majority of experimental aircraft. The reason for this: kit manufacturers couldn't compete in the marketplace if they were constantly sourcing obscure and costly hardware. So, rather than writing about the hundreds of different types of bolts available, we want to focus on the basic bolts used on the majority of experimental aircraft built today. The Standard Aircraft Machine Bolt is the (AN3 through AN-20). The "AN" in the part number identifies that these particular bolts conform to a specification called the the Air Force-Navy standards. The first number refers to the diameter of the bolt in 1/16ths of an inch.(Figure: 1) The "dash" number refers to the length of bolt in 1/8ths of an inch. When we reach lenghs greater than 7/8 of an inch, we refer to the first number as the number in whole inches and the second number in 1/8ths of an inch. For example, a 1 inch bolt is a -10, a -20 = 2", and a -35 = 3 and 5/8". Now that we have explained the basic numbering system for the length, it is important to point out that this is a generic numbering system. In reality, both the length and the grip of the bolts vary depending on diameter. This is the reason that it is essential to use a bolt gauge when measuring the length of bolts and using a bolt chart when ordering. With that said, let's look at some simple modifications to the bolt and subsequently the part number. There are two basic machining options available to the basic AN bolt. The first is a drilled hole in the shank, which allows the use of a cotter pin and castle nut. In this case, the addendum to the part number can be rather counterintuitive. If we would like to pur-

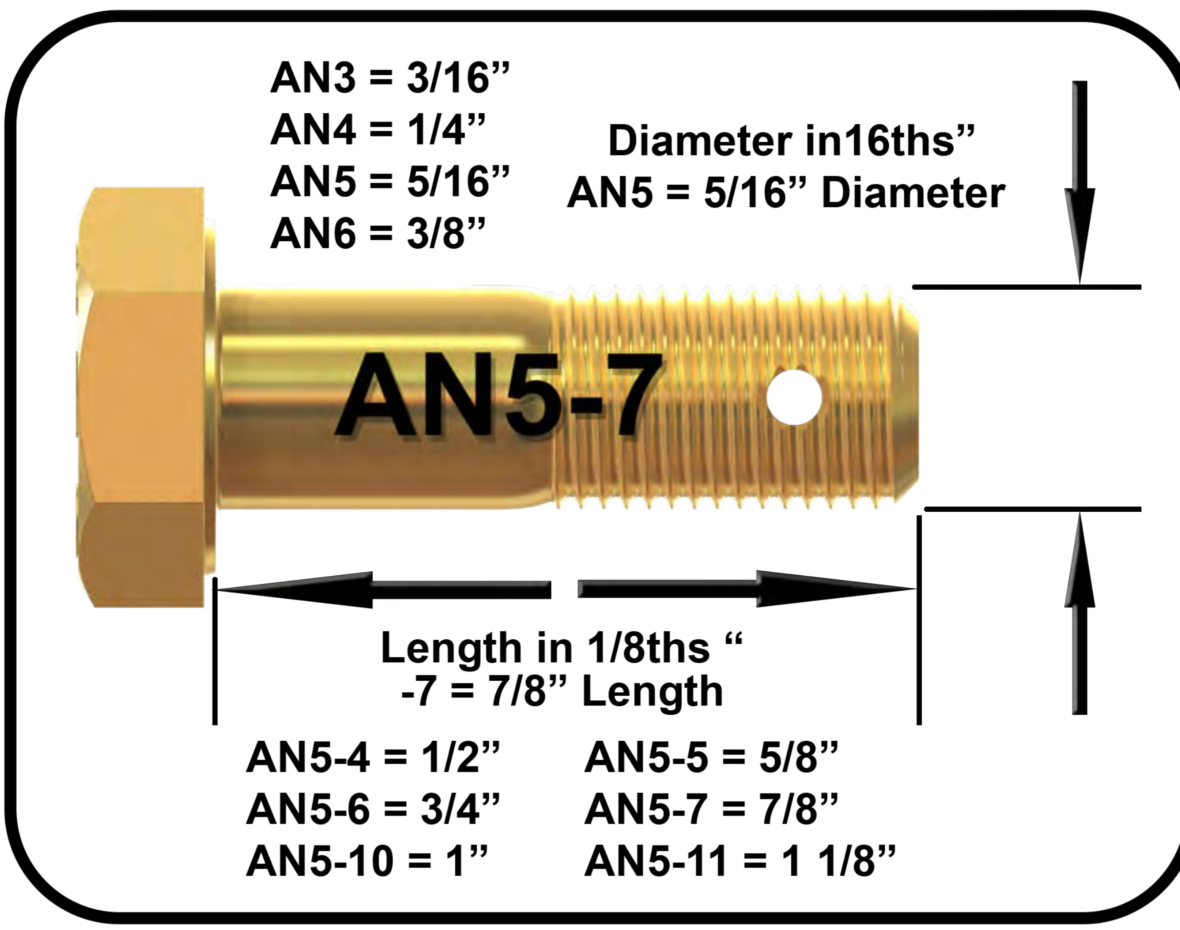


Figure: 1 Bolt Sizing

chase a bolt without a hole in the shank for a cotter pin and castle nut, we are required to add an "A" to the end of the part number (for example AN5-7A). Without the "A" the bolt will automatically have the whole drilled in the shank. (Figure: 2) The second modification is the drilling of the bolt head for the purpose of safety wiring. This part number addendum makes a bit more sense. We simply add a "H" after the basic part number, but before the dash number, for a bolt with a drilled head (for example AN5H-7A). You may also find several references that leave the "dash" out of the part number once the basic part number has been modified with a letter (for example AN5H7A).

Figure: 2 Safety Wire and Cotter Pin Holes

Last, but not least, there is one more possible modification to the AN bolt. Not a machining modification, but rather a materials modification. (Figure: 3) The "Standard Steel" AN bolt standards call for a high strength 8740 alloy steel, with a tensile strength around 125,000 - 145,000 PSI. These standard bolts are centerless ground and roll threaded after heat treatment, then cadmium plated. It is this gold iridescent cadmium plating that makes the standard steel bolt easy to identify at first glance, but it is the head markings that we use for positive identification. The "X" stamped or raised onto the head of the bolt is the primary identifier of a standard steel AN bolt. to the uninitiated this can be quite confusing. Pick up just about any AN bolt and you will see all manner of markings. These

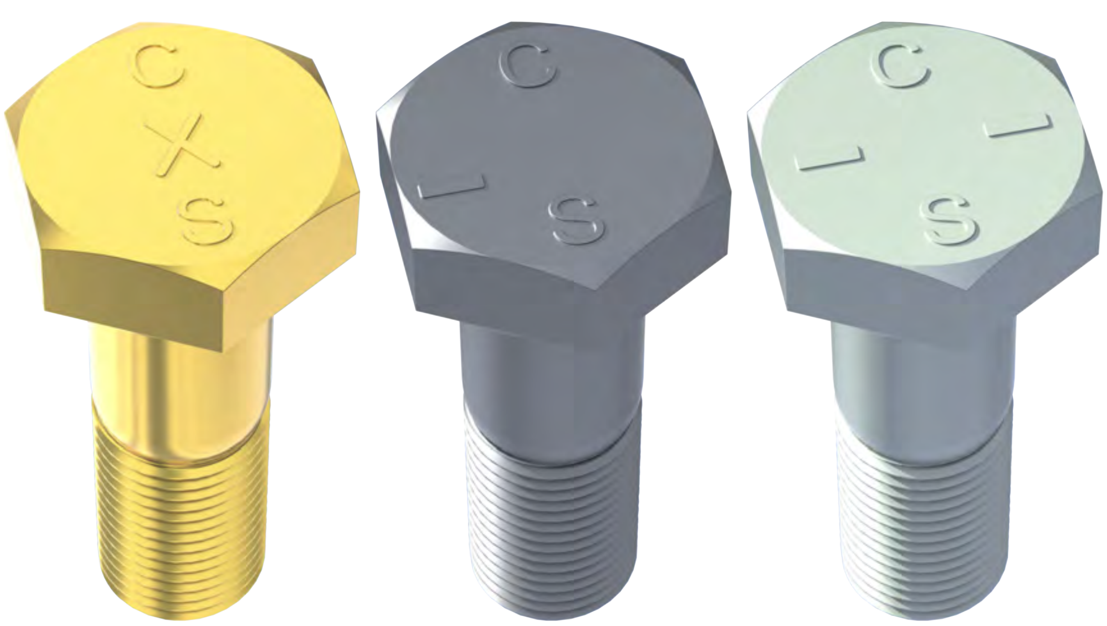


Figure: 3 Bolt Material Composition

markings are manufacturers identification markings. (Figure: 4) For this article we searched the shop and easily found a selection of dozen different manufacturers on just AN5 bolts. At random we selected a bolt for 3D modeling with “CS” emblazoned on the head. Afterwards, we were able to look up and identify the manufacturer as California Screw Products. Generally, it’s pretty easy to distinguish the manufacturers marks from the material identification markings.

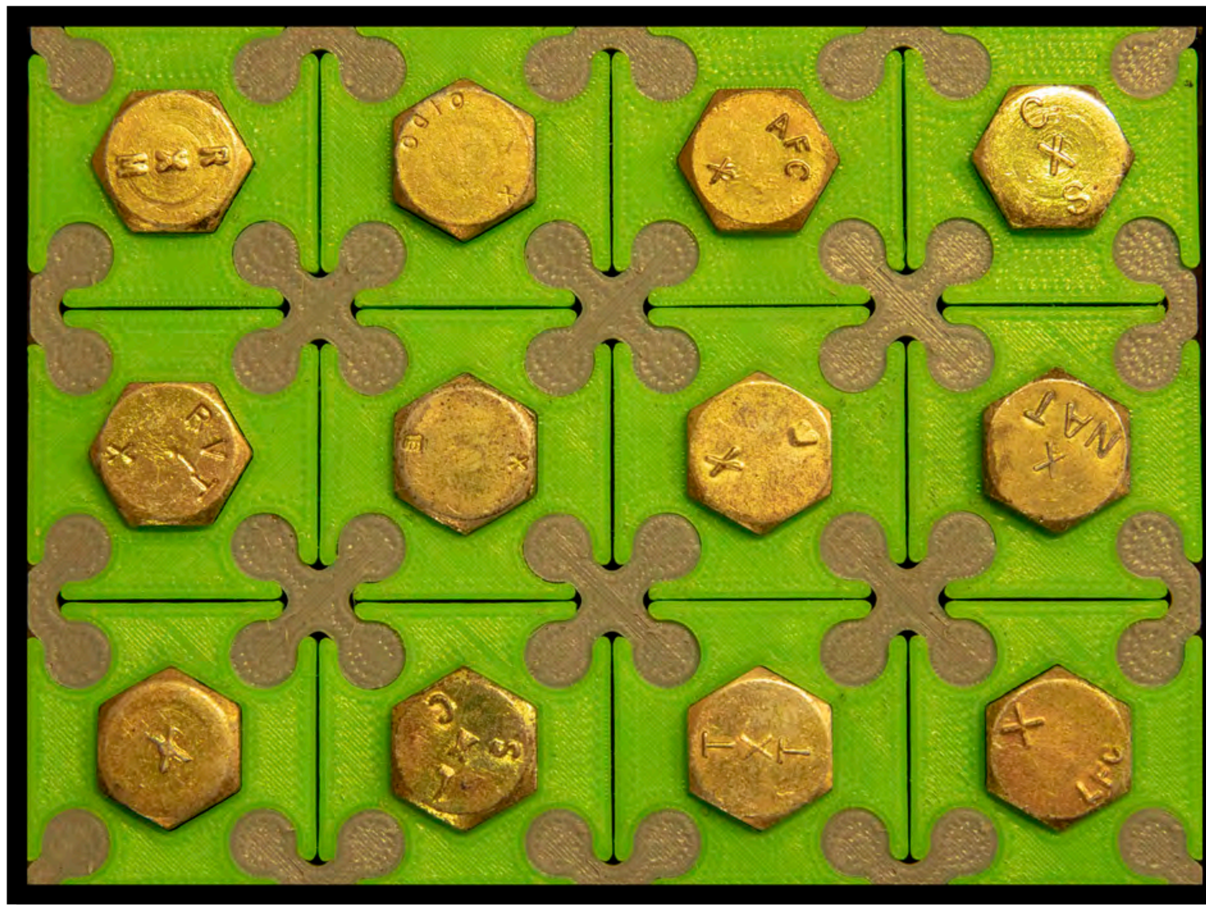


Figure: 4 *AN5 Bolts From Various Manufacturers*

There are only three materials and subsequently three markings to identify. We have talked about the “X”, so let’s move on to the next material. Corrosion resistant steel is identified with a single raised or recessed “Dash” (–) marking on the head. In addition, the corrosion resistant steel is un-plated, and sports that gunmetal gray color that make the material easy to Identify at a glance. The addition of the “C” after the basic part number identifies the bolt as a corrosion resistant steel bolt (for example AN5C-7A). These bolts are manufactured from 431 grade stanless steel. This is a martensitic grade straight chromium steel containing no nickel, and as a result, quite magnetic. 431 is used for its combination of hardness, strength, and wear resistance while still retaining superior corrosion resistance properties. The tensile strength is around125,000 psi. Juxtaposed to the two steel bolts we have the 2024 aluminum alloy bolt with a tensile strength of around 62,000 psi. This bolt is also readily identifiable. The anodized color is the first clue. In contrast to the other two steel bolts, the aluminum bolt is nonmagnetic. However, the dead giveaway is when you pick up an aluminum bolt it is dramatically lighter than you would anticipate. To positively identify the bolt as an aluminum bolt the head markings are a “double dash” (- -). The addition of “DD” after the basic part number identifies the bolt as and aluminum bolt (for example AN5DD-7A).

AN-3	**32 TPI**
AN-4	**28 TPI**
AN-5	**24 TPI**
AN-6	**24 TPI**
AN-7	**20 TPI**
AN-8	**20 TPI**

Figure: 5 Thread Pitch

Let’s also identify some characteristics that are universal to all of these bolts. The standard AN bolt thread is the ‘Unified National Fine’ (UNF) thread. (Figure: 5) This is based on a 60° thread that forms an equilateral triangle with the exception that the root of the threads are rounded during the thread rolling process. Rolled threads minimize stress concentrations and significantly enhance the strength across the threaded section of the bolt. It is literally the difference between forging and machining a piece of metal. (Figure: 6) Cutting additional threads with a die is considered a major faux pas. This is because the pointed end of a die is cutting into the material leaving a stress concentration.

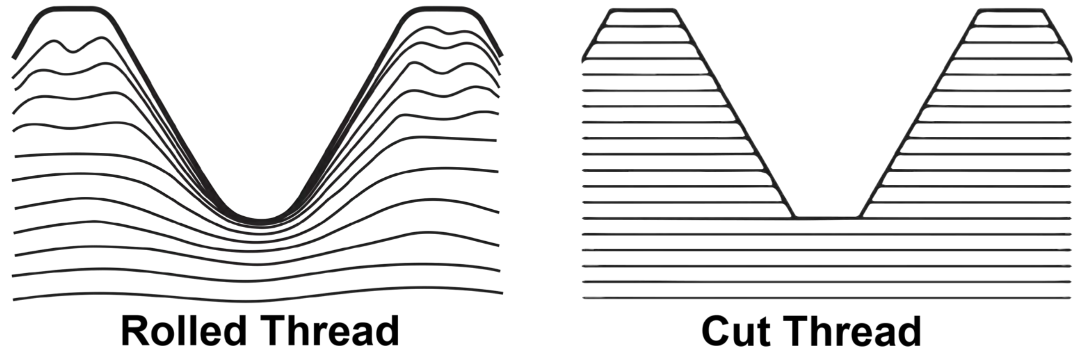


Figure: 6 Rolled vs Cut Threads

Notes on Torqing Bolts: Unless otherwise specified, for a particular installation, the bolts should be torqued “Dry”. It is interesting to note that only about 15% of the torque applied during the torquing process increases the bolt tension. But around 45% of the turning force is required to overcome the friction between the male and female threads. Any oil, anti-seize compound, or other lubricants present on the threads during the torquing can significantly reduce the friction. This can lead to a significant increase in the actual tension applied to the bolt, even to the point where the tension on the bolt is stressed beyond its yield point. This could easily lead to possible premature failure. The cadmium plating on the standard steel bolts, for corrosion protection, also acts as a lubricant. The standard torque table specifications take this into account and no adjustment is needed. But it brings up the point, installing old rusty hardware with the cadmium plating missing may actually lead to a reduced torque value as a result of increased friction at the thread interface.

The purpose of torquing the bolt is to apply a preload. This has the effect of reducing the bolt’s exposure to fatigue cycles. When using lock nuts, either nylon or all metal lock nuts, there is a friction drag component created by the locking device. On critical application bolts, it is common practice, to measure the friction drag torque required to turn the nut, and then add that value to the desired torque setting to come up with our “final torque”. Additionally, structural assemblies exposed to continuous flight loads may “settle in”, reducing the preload on the bolt. Additionally, components exposed to thermal cycling or installed with a gasket may also lose their preload. This is primary reason that a manufacturer may call for a re-torquing interval to once again establish the proper preload on the bolt.

The AN Bolt is nearly as old as aviation, and it is the backbone of the aircraft construction process. If you’re thinking of building your first aircraft, you will inevitably become friends with this venerable piece of hardware. And if you’ve already built an aircraft, it’s always good to get reacquainted with a friend, especially if that friend is holding the wings onto the rest of your aircraft.

Although the practice of safety wire itself is not particularly difficult, the chasm between casual practice and precision execution could easily fit a Boeing 747. Even the participants in our repairman workshops with aviation backgrounds often require many hours practice to master the basic do's and don'ts of safety wire. And practice, practice, practice is the only solution for developing efficiency and that "attention to detail" type of craftsmanship which is essential in an award-winning aircraft. Even if you're not looking to win the "Lindy" award, details like safety wire tell us a lot about the mindset of the aircraft builder or mechanic. Anecdotally, over the years, we have seen a very strong, positive correlation between safety, aircraft reliability and the builders who put the effort into the details.

More often than not, we see safety wire installations that in practice will probably work, but strictly speaking are done with poor execution. In researching for this article, we found more cases of improper safety wire procedures, than we found examples of safety wire done correctly. By definition, safetying is "Securing by various means any nut, bolt, turnbuckle etc., on the aircraft so that vibration will not cause it to loosen during operation." This runs contrary to the mindset that the safety wire is used to hold the part from falling off of the aircraft after having come loose. Only proper technique can ensure that the fastener will not come loose during normal operation.

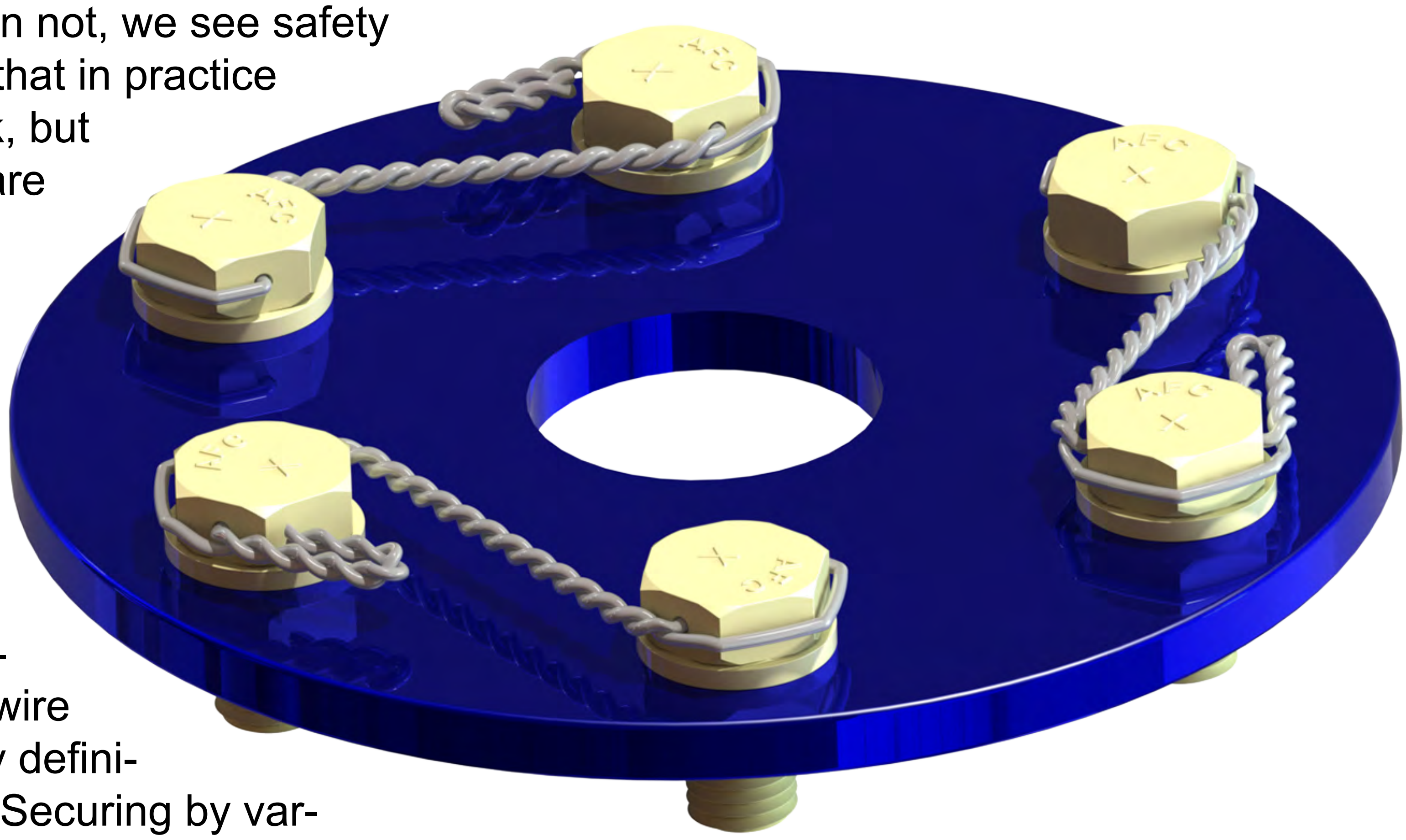


Figure: 1 The Standard Twist Method of Safety Wire

There are two methods of safety wiring; the first is the double-twist method. Figure: 1 & Figure: 2. This is most commonly used method of safety wiring. The second, and less often used method, the single-wire method. The primary downside to the single wire method is that a failure of the wire will affect all of the fasteners simultaneously. When using the single-wire method, use the largest safety wire consistent with the size of hole in the fastener to be safety wired. This would typically be used on screws, bolts, and/or nuts in a closely spaced or closed-geometrical pattern, or in

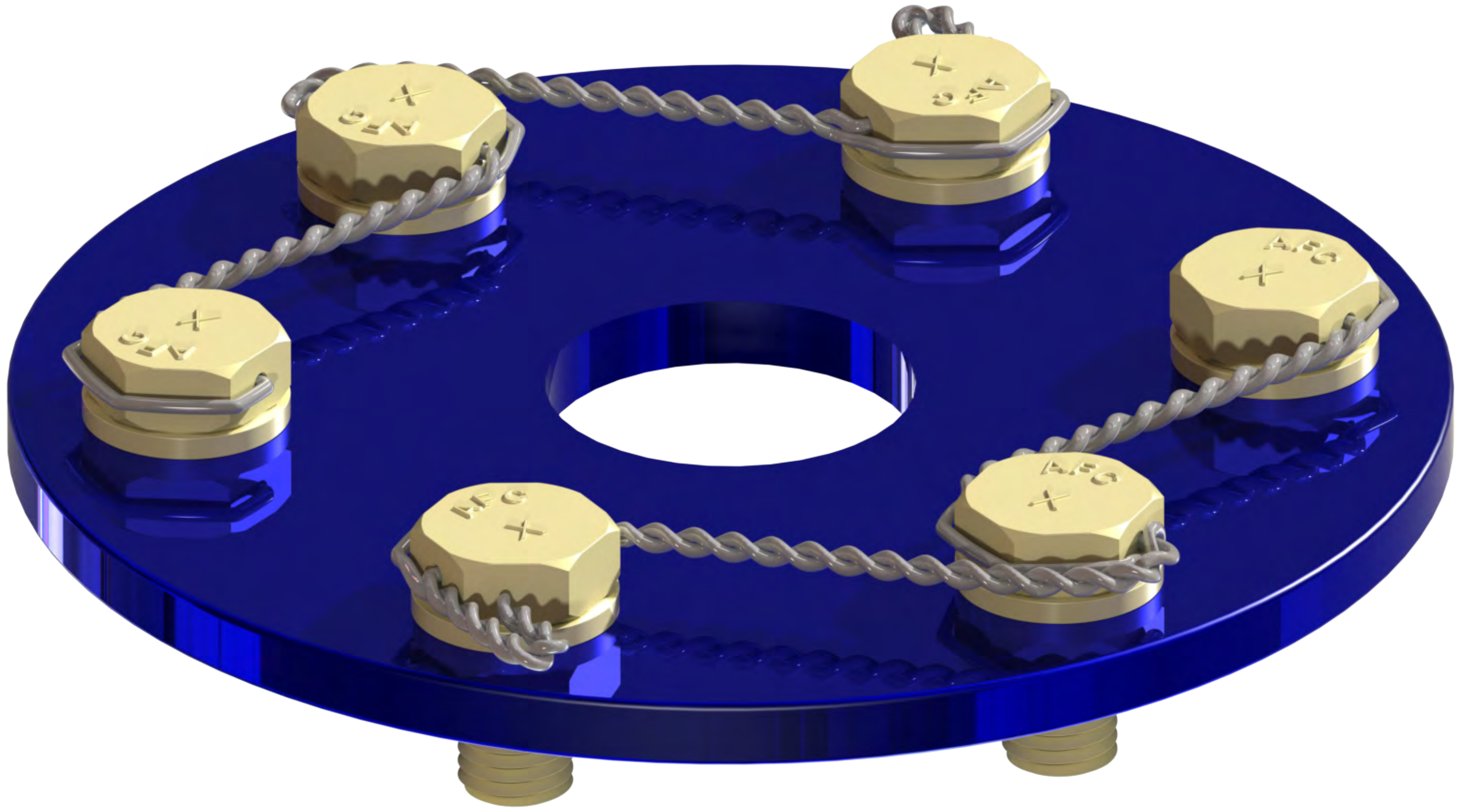


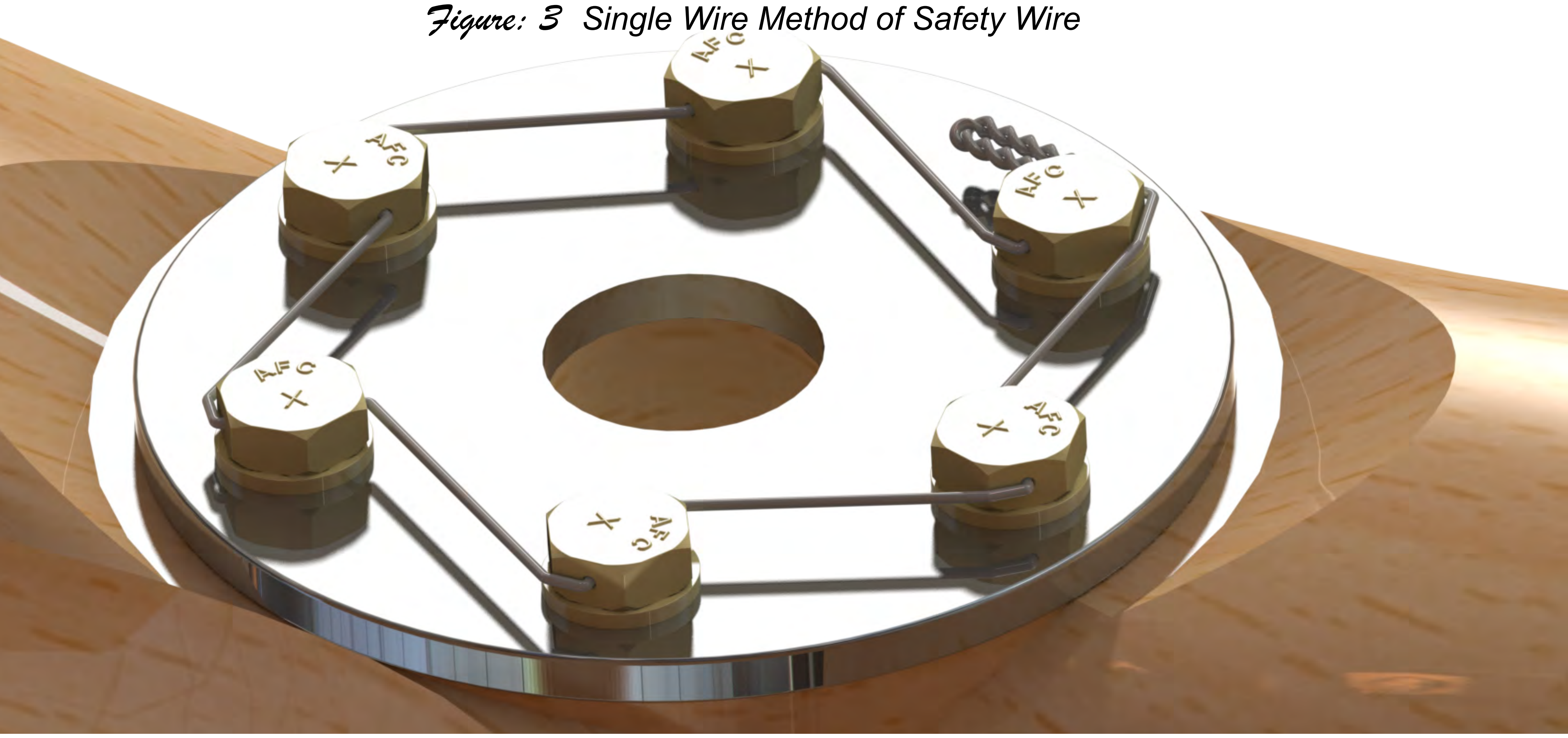
Figure: 2 The Group Twist Method of Safety Wire

places that are difficult to reach.

The Basics Rules for Safety Wire

Before beginning the safety wire procedure check, ensure that the fasteners have been properly torqued. The prime directive regarding safety wire is that it must be installed in a manner that will prevent the tendency of the part to loosen. This includes ensuring that the safety wire is routed in such a fashion as to tighten the fastener. Remember “Lefty Loosey - Righty Tighty”. Figure: 4. Upon initial inspection, we can generally identify that the safety wire has been installed with the correct orientation (tightening direction) by the telltale reverse S.

Figure: 3 Single Wire Method of Safety Wire



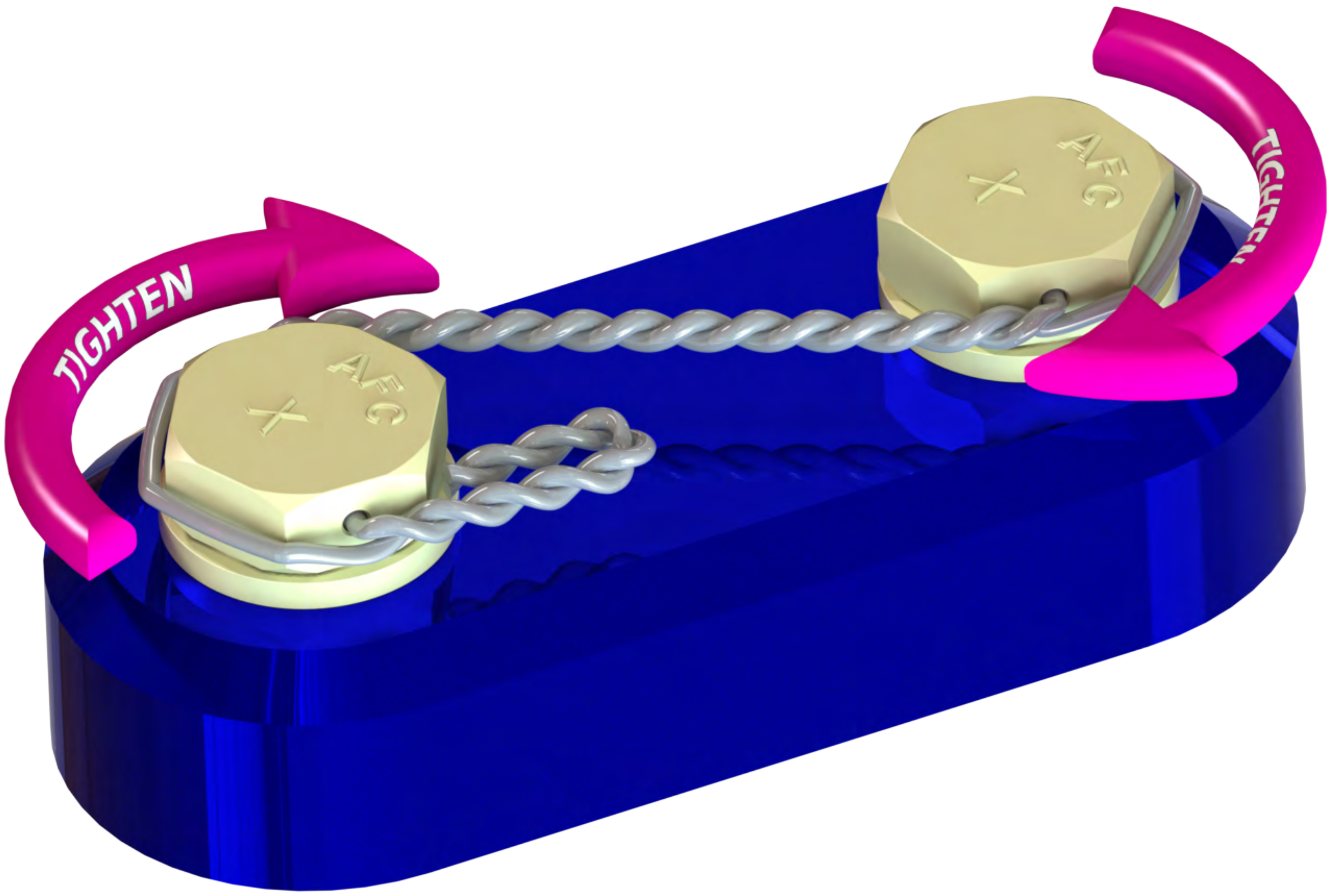


Figure: 4 Safety wire in a clockwise rotation to tighten the fasteners

pattern of the safety wire. Safety wire must be pulled taut when being twisted, and main-tain a light tension when secured. This serves the purpose of both preventing the part from loosening as well as preventing the failure of the safety wire due to rubbing or vibration. Although proper tension is of utmost importance, this is one area where you don't want to become overzealous. Safety wire must never be overstressed. Safety wire will break under vibrations if twisted too tightly.

Do not reuse safety wire. Safety wire is cheap. Safety wire must not be nicked, kinked, or mutilated. This includes the damage that you do during the installation process. If you found that you messed up the safety wire during installation simply cut it off and start over again. Remember, the only way to not have a professional looking safety wire job is to give up and accept mediocrity before you achieve perfection.

Use the appropriate size of safety wire for the job at hand. If you own an airplane you should have at least the three, following, primary sizes of stainless steel safety wire in your toolbox. .020" used for small jobs. Things like electrical cannon plugs, and small accessories. .032 is the most common and widely used safety wire. And .041 for heavy-duty safety wiring used for items like prop bolts, internal engine components, primary flight controls, and exhaust springs on Rotax engines. Figure: 5

The Double Twist Method.

STEP 1. Figure: 6. Position the safety wire so that both of the non-twisted strands

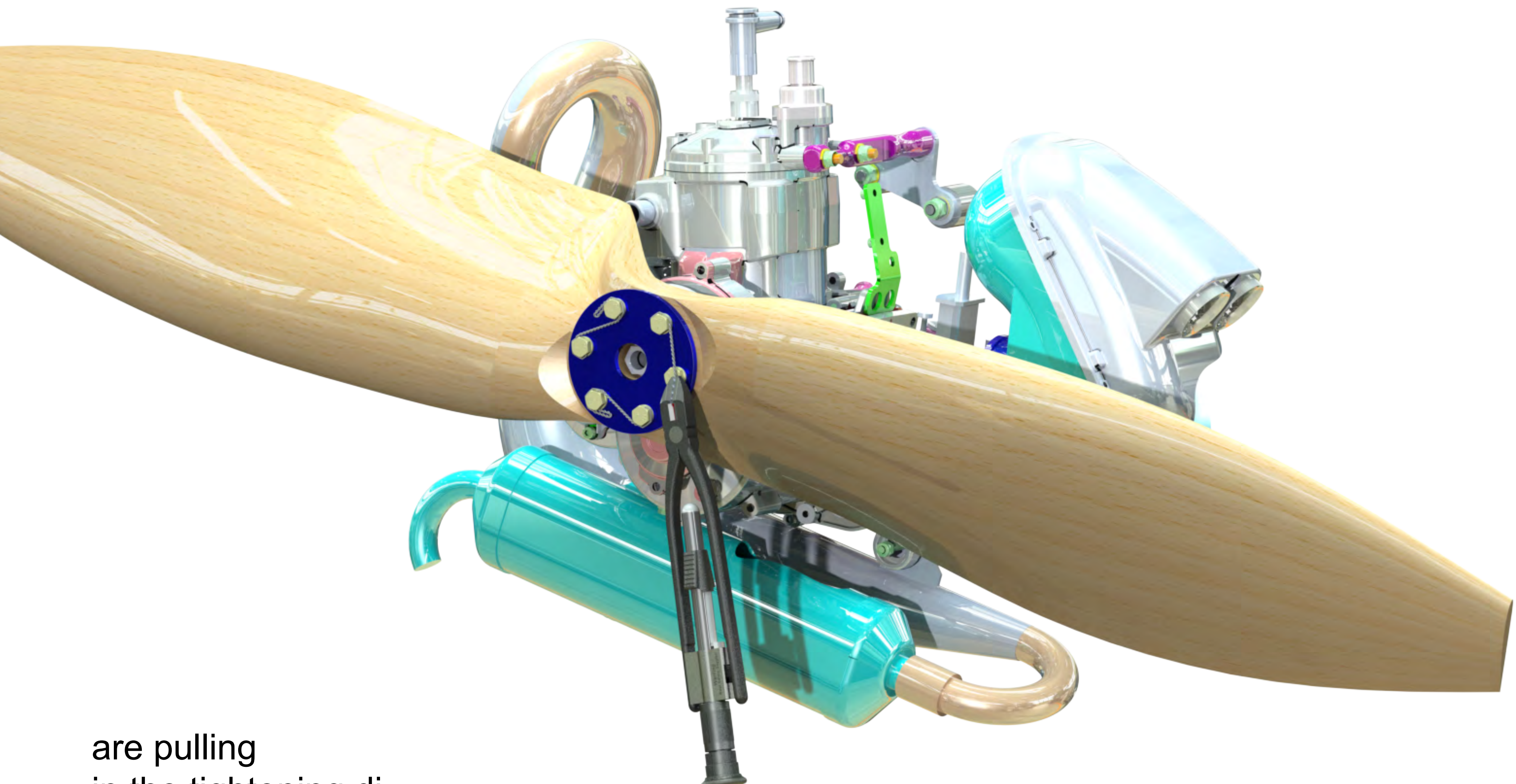


Figure: 5 Use of .041” Safety Wire for propeller bolts

are pulling in the tightening direction. The single wire through the fastener and the loop around the perimeter should always be pulling in the tightening direction. The direction of twist is what determines to which side of the fastener the loop will naturally lie. This means that the first twist will always be a clockwise twist. The twist should begin precisely at the through hole in the fastener. This can be achieved by properly positioning the safety wire pliers approximately 75 to 80° from the through hole in the fastener before pinching the wires to begin the twist. **STEP 2.** Position the safety wire pliers so that the twisting will not extend beyond the next insertion hole. Now twist the safety wire pliers to achieve 6-8 twists per inch. **STEP 3.** Insert the single wire on the top of the twist through the bolt through hole. Wrap the lower wire around the perimeter of the bolt head so that both wires are pulling the bolt in the tightening direction. Now reposition the safety wire pliers to achieve the 75 to 80° angle from the through hole and begin twisting once again. This time, however, you will need to be twisting in a counterclockwise direction which will naturally tend to lay the loop around the perimeter of the bolt down against the base of the bolt head. The first twist will always be clockwise and the last twist will always be counterclockwise. In addition, the twisted wire will always start exactly at an exit hole and always end the twist exactly at the hole of the next fastener. A twisted wire not starting or stopping at an insertion hole is a clue that the technique was in error. **STEP 4.** We now need to cut the wire to the proper length. Professional safety wire pliers typically have a set of rubber jaws located adjacent to the cutter. These jaws clamp the remaining safety wire during the cutting process so that the ends do not get lost inside the aircraft. **STEP 5.** Safety-wire

ends must be bent under and inward toward the part to avoid sharp or projecting ends which might present a safety hazard. AC 43.13-1B (the FAA advisory circular for acceptable methods and practices) recommends a minimum of 4 to 6 complete turns for the cut off end. This is great if the ends do not need to be bent more than a few degrees. However, you will find a much cleaner product when you leave a longer tail when bending a tail 180° back onto itself as in shown in STEP 6.

Tips and Tricks

First Hole Cheat. On occasion you may have a hole in the head of the faster that seems just impossible to get access for safety wiring. If it is the first fastener in the series to be safety wired we can loosen that fastener, install the safety wire, and then re-torque the fastener into its proper position. This, of course, can only be done on the first fastener, but still, it provides an option with very difficult to reach fasteners.

Hardest first. This is also one of the reasons that we start the safety wire in the most difficult position and work our way out to the easiest access fastener to finish up the final twist.

The “Woop-Dee-Do” Maneuver. This is a great trick for getting that twist tightened up. This involves

Figure: 6 “Double Twist” safety wire Procedures twisting the safety wire pliers 90° by hand while simultaneously making about a 2" circular motion with the tip of the safety wire pliers. This will force the twist to occur at the beginning of the twist near the exit hole rather than at the end of the twist where the wire pliers are located. Use this technique judiciously as overuse can easily over-stress the wire.

Thin Washers: Washers may be used to establish proper alignment. On occasion the safety wire holes just don't align in such a way that is conducive to proper safety wiring. A good way to introduce a slightly different alignment is the use of AN960 washer with the letter "L" added to dash number (AN960-416L). This indicates light series or thin washer. Often times, simply trying another bolt will permit proper alignment while staying within the specified torque limits. You should stay away from under-torquing or over-torquing to achieve proper alignment.

Safety Wire Pliers. Although it is not necessary to own a pair of safety wire pliers in order to do a professional job of safety wiring, you will find them invaluable if you do much safety wire work. This is where quality is worth the cost. There's nothing that will make you appreciate a good pair of safety wire pliers more than spending a couple of days working with a cheap pair. The small 6" safety wire pliers are really cute, but really only work well when using .020" safety wire. You will find the larger safety wire pliers much more versatile. A professional pair of safety wire pliers that are reversible and have the rubber insert in the jaw to catch the safety wire can easily run over $100. Worth every penny.

There is a lot of satisfaction with accomplishing any task that results in quality workmanship. Safety wiring skills are no exception. Perhaps a second look at your latest safety wire job is warranted. After all, Safe flying is NO accident!

Carol and Brian Carpenter are owners of Rainbow Aviation Services in Corning, California. For more Information visit www.rainbowaviation.com

Avgas vs Mogas in Light Sport Aircraft (Part 1)

RAINBOW Aviation Services™

One of the most requested topics, for us to weigh in on, is the subject of Avgas (aviation fuel) versus Mogas (automotive fuel) in light sport aircraft. This is also one of the more controversial subjects that makes it very difficult to write an article that is "definitive" on the subject. We often get questions like "what type of fuel should I be using in my light sport aircraft?" This is akin to the question, "do these pants make me look fat?" Your first instinct should be to change the subject as quickly as possible. And, god forbid, you do elect to engage, you need to recognize that the conversation is going to morph into many other unrelated topics, and nothing you say is going to be an acceptable answer. Several years ago, we did a two-hour presentation on the subject for the RV-12 fly-in in Bend Oregon. The first hour of the presentation was all the reasons that you shouldn't use Avgas in your Rotax engine, and the second hour of the presentation was all the reasons that you shouldn't use Mogas in your Rotax engine. (Figure: 1) Well, "that wasn't very helpful," was it? But it was, kind of the point. If there wasn't a downside to a particular fuel, it would be a "no-brainer" for everyone just to select that particular type of fuel. And for the manufacturer of each engine and each airframe to recommend only one type of fuel as well. So, in reality, it is a matter of choosing the fuel for a particular mission profile that provides the least number of downsides. Or if you like, the fuel that is best suited for your mission profile. When we use the word "mission profile" we are talking about a particular set of operating circumstances. Your mission profile may change throughout the year, and as a result, the type of fuel you may want to use will also change. It is important to identify the downsides of each type of fuel in order to make a judgment about how it will impact your airframe and engine under these operating conditions. Because each fuel has its own downsides, it is important to understand what additional maintenance or operating conditions need to be performed in order to mitigate or eliminate any po-

Avgas Downsides

Tetraethyl lead
Expensive

Mogas Downsides

Alcohol and Methanol
Effect on Composite Materials
Short Useful Life
Vapor Lock
Different Formulations
Accessibility

Figure: 1 Downside of Avgas and Mogas

tential problems that may arise from each of the two very different types of fuel.

In an effort to emulate our two-hour presentation on Avgas versus Mogas, let's start off with the downsides of Avgas. On our list of downsides, we have simplified the list in to two primary reasons for not using Avgas: Tetraethyl lead, and cost.

Tetraethyl lead is the primary concern when utilizing aviation fuel. Tetraethyl lead is the additive that is added to aviation fuel which provides the anti-detonation properties (octane). This stuff forms deposits that can over time cause problems in different ways. It tends to foul spark plugs, build up deposits on the pistons and rings, and generally sludge up the oil system. Even as late as 2004 Rotax was still fighting the battle of operators using the wrong type of oil in conjunction with Avgas.

In their ongoing attempt to provide more guidance on the proper type of oil to use for each mission profile, Rotax issued service instruction SI-18-1997 R5 (now superseded). In the body of that text for the service instruction they provided a simple summary of the problem. "The lead content of currently available leaded AVGAS fuels is very high. The 100 LL AVGAS commonly available in North America contains up to 0.58 ml / litre of tetraethyl lead, more than 4 times the lead found in the leaded 80/87 AVGAS previously available. Due to this extremely high lead content, residue formation leading to operating difficulties with valve and piston ring sticking and cylinder wall glazing occurs more frequently when engines are primarily operated with leaded AVGAS fuels. Lead deposits could cause glazing of the cylinder walls."

It wasn't so much a problem exclusively with the Avgas, but rather the multitude of different oils that operators were experimenting with in conjunction with the Avgas. Well, even this updated service instruction didn't put the issue to rest, and as a result, we are currently working under service instruction-912-016R10. This latest endeavor to improve reliability and safety involved partnering with Aeroshell to develop an oil (AeroShell Oil Sport Plus 4) that is specifically designed for the Rotax 9 series engines. AeroShell says "It is designed to cope with the high shear stresses associated with integrated gearboxes and overload clutches, and has detergents that help to keep critical areas, such as pistons and cyl-

Figure: 2 AeroShell Sport Plus 4

inders, clean". All the other oils that operators had been using for years, are now absent from the list of approved oils. And the AeroShell Sport Plus 4 oil is now the only oil recommended by Rotax for both Avgas and Mogas. It appears that Rotax is banking on standardization to prevent many of the ill-fated experiments that were ongoing in the past.

Not only that, it allows Rotax to work directly with AeroShell to make any "tweaks" that are necessary to improve performance and reliability as time goes on. And yes, we have seen that happen already. The newest formulation of Sport Plus 4 oil now comes in a red bottle instead of the previous version which was supplied in a black bottle. (Figure: 2) This oil is great at holding the tetraethyl lead in solution so that it can be extracted from the engine at oil change.

In the early days we used to take and airplane in for annual, and if the owner was using some obscure oil, we would take an oil sample in a quart jar and watch the tetraethyl lead fall out of solution and settle on the bottom of the jar literally within hours of taking oil sample. Not Good. Conducting the same test using the AeroShell oil shows no separation even after many months of sitting. One of the other methods that Rotax employs to mitigate the effects of tetraethyl lead, is to change oil on a more frequent basis. The Rotax maintenance manual gives good guidance on the oil change interval depending on the percentage of Avgas used. The premise is that changing the oil more frequently will reduce the amount of tetraethyl lead that the engine is exposed to.

Everyone agrees, that the tetraethyl lead is the downside of Avgas. And even in the conclusion of the most recent Rotax service instruction, they state, "Conclusions: - If possible, operate the listed engine types using unleaded or low-lead fuel. (AVGAS 100 LL is not considered low leaded in this context.)" This statement makes it pretty clear that Rotax favors the use of automotive fuel over 100LL.

The second item on our list of downsides for Avgas is cost. Not just the cost of fuel, but the cost of doubling up on your oil changes, and the increased maintenance costs associated with operating 100 LL. Even if you are of the mindset that cost should not play a role in the decision of which fuel to use, we must bring the total cost of operation variable into the equation. For many people, the cost of operation can be the tipping point between flying and not flying. The $100 hamburger used to be considered a joke. Nowadays, it is more like an aspirational goal that is often dreamt about, but seldom achieved. The cost of fuel is a significant portion of the operating cost on any airplane.

The good news is, that the vast majority of light sport aircraft use engines that are literally sipping fuel compared to our big Lycoming and Continental brethren. And using automotive fuel in lieu of aviation fuel can improve the bottom line of the operating cost. But only when it makes sense. So far, in this article (Part 1), all we have talked about is the downside of Avgas. If, while reading this article you've come to the conclusion that "avgas should not be used on a Rotax 912 engine", hold your horses. If you think we painted a bleak picture here, wait till we talk about the use of automotive fuel in light sport aircraft and engines.

In (Part 2), we will do just that. We will talk about all the downsides to using automotive fuel and show you some of the reasons why you may think “Automotive fuel should not be used on a Rotax 912 engine”. The good news is, it’s not the end of the world. Never fear. We will help to sort out when it would be a better idea to use one type of fuel over the other. And what to do to mitigate the negative effects of each type of fuel. And when approached appropriately, there isn’t any reason why your engine can’t reach TBO using either of these two types of fuel.

Last month in part 1 of this article, we looked primarily at the downsides of using 100 low lead fuel. In this article, we will look a bit more in depth about the use of auto fuel or "Mogas" as it is often referred to.

We identified in the previous article that Rotax allows both the use of Avgas as well as Mogas. However, it was clear that in all the service bulletin and maintenance manual information available from Rotax, there was some significant concern and operating recommendations to mitigate the negative side effects when using highly leaded aviation fuels such as 100LL. Working with the premise that Rotax favors the use of Mogas over Avgas, begs the question, why would we not always use Mogas in our Rotax engines? Well, that's exactly what we're going to address in this article.

Methanol and ethanol are the two most common alcohols used in automotive fuel today. And like the bigger topic of Avgas versus Mogas, there are both upsides and

Figure: 1 Corrosion on a Bing carburetor main jet and mixing tube downsides to their use. Both of these alcohols have a relatively high octane rating, approximately 109 RON (Research Octane Number), 90 MON (Motor Octane Number), which equates to approximately 99 AKI (anti-knock index). And due to their lower carbon-to-hydrogen ratios, these fuels have lower toxic emissions an improved engine efficiency.

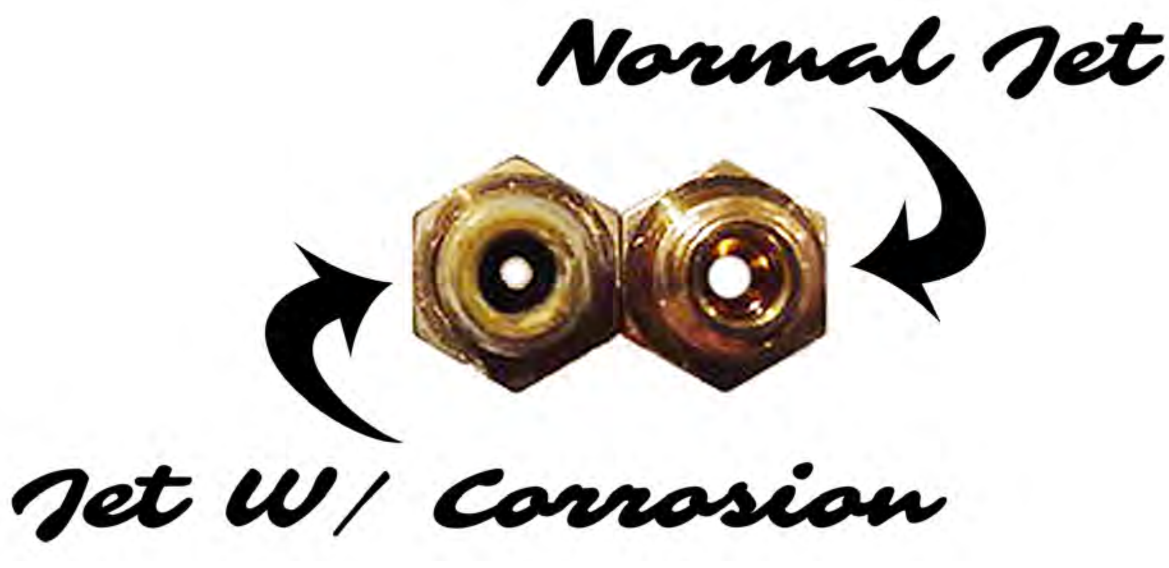


Figure: 2 Main Jet Hole Diameter

Now for the downsides. Both fuels contain what are called halide ions. Halide ions are primarily responsible for the increased corrosivity of the fuels. Both from a direct chemical attack as well as increasing the conductivity of the fuels promoting increased galvanic, and direct electro-chemical attack. To make matters worse, ethanol is hygroscopic and readily attracts water from its surrounding environment. Whether you consider the resulting corrosion primarily attributed to the ethanol, or the water, is kind of a moot point when considering the final result.

(Figure: 1) Shows an example of corrosion within a Bing carburetor float bowl mounted on a Rotax 582. This condition is the result of only a few months exposure to ethanol-based fuel. The oxidation of the brass caused formation of deposits on most of the jet, but more significantly on the inside diameter of the main jet. This reduced the flow of fuel through the main jet. You can think of it as a partially clogged drainpipe reducing the flow of water in your sink drain. However, in this case the flow through the main jet caused a lean fuel-air mixture and subsequent seizure of the cylinder associated with this carburetor. (Figure: 2) Regardless, it's safe to say that corrosion within your fuel system whether it is in the fuel tank, fuel pump, fuel lines, or carburetor is a high-risk bullet point that we would like to avoid. If you happen to to have access to fuel without ethanol, consider yourself fortunate. Many operators of light sport aircraft are not so lucky. If you're having troubles finding non-ethanol fuel check out PURE-GAS.org. Out of the 14,000 stations listed only 20 show up for the entire state of California. Our little town of Corning is one of the lucky ones. When E10 first became the new normal, the Rotax engines were only authorized to use a maximum of 5% ethanol. It took Rotax many years to become accepting of the new 10% ethanol standard. Which it now authorizes in its maintenance manual. And we only bring this up because in recent months, we have seen the EPA fast tracking modifications to legislation which would allow the use of E15 fuel to be sold year-round without any additional modifications to the Reed Vapor Pressure (RVP) requirements. It will be interesting to see how Rotax addresses the E15 fuel.

Figure: 3 The “Ranger” aircraft designed by Brian, circa 1995

Both ethanol and the aromatic hydrocarbons that are in gasoline (such as benzene, toluene, and xylene) have shown to be incompatible with some polymers. Many of these aromatic hydrocarbons have been shown to reacts with a variety of polymers causing swelling and in many cases breaking down the carbon-carbon bonds in the polymer causing a reduction in tensile strength. When we say “polymers”, we are talking about a wide variety of materials, but for our purposes, primarily parts that are rubber and plastic within our fuel system as well the resins and epoxies used in composite structures. We had a great example of how these compounds affected rubber when we switched from 100LL to auto fuel in the “Ranger” aircraft. (Figure: 3) The aircraft had set for nearly a month after the first introduction to auto fuel, and when we were preparing to fly the aircraft again after this period of inactivity, we found that rubber on the fuel caps had swollen up so much that it was nearly impossible to remove them. After switching back to 100LL the rubber returned to its natural state, and was there ever after, functioning as designed. In the early days of the auto fuel STC’s (supplemental type certificates), many aircraft we worked on, experienced the same type of problems, but on a much more intense level. We often used to joke, that the added maintenance costs would typically exceed the fuel savings for at least the first year. However, once all the hoses, gaskets, O-rings, and the general fuel system components had been converted to components that were compatible with auto fuel, the vast majority of problems began to dissipate. And ironically the bulk of these problems were directly related to owners using ethanol-based fuels, which were never approved fuels per the STC.

The one area that continues to haunt the light sport community, is the use of auto fuel in conjunction with composite fuel tanks. Many of the older types of epoxy worked well with auto fuel up until the formulations changed and began to incorporate the use of ethanol and increased percentage of aromatics even on the non-methanol

Figure: 4 Fuel contamination from a composite fuel tank.

containing fuel (E0). Often times it isn't obvious that there is a problem until several years have passed and we start to see the results of the fuel degrading the composite structures. Manufacturers of new aircraft have started to take this to heart and our employing many new techniques to mitigate the effects of the new formulations of fuel, including new types of epoxies, and the use of fuel tank sealing compounds that are compatible with the myriad of chemical compounds found in modern fuels. And although, there are new aircraft that occasionally have problems, the vast majority of auto fuel related fuel tank problems relate back to the older aircraft. For many years now, we've had a standard recommendation that if you have a composite fuel tank or more importantly a composite aircraft with a "Wet Wing", we recommend avoiding auto fuel unless the manufacturer specifically authorizes the use of auto fuel. (figure 4) shows the float bowl off a Rotax 912 where the fuel tank epoxy is literally coming back into solution, coating, sticking, and gumming up the fuel filter, fuel pump, fuel valves, and the carburetor. Who knows what kind of damage could have been done to the engine itself if it were able to run with fuel contamination of this severity. Even after flushing the fuel tanks several times and reverting to 100LL, the carburetors continued to need disassembly and cleaning several different times over the course of a month because of what was obviously contamination from the original epoxy problem. The other area that is really hard to pin down, is the myriad of magic potion additives that owners' experiment with. We are often suspicious when we see one-off problems that are related to the fuel system, especially when we know the aircraft owner has been watching way too many late-night infomercials. When you decide to take on the role of the chemist, who knows what you might end up with when combining all those different chemicals together. Remember, if the engine and airframe manufacturer do not recommend your favorite additive, you are now part of the research and development team for this particular product on your particular aircraft and engine.

As a final thought about automotive fuel we need to talk about its relatively short shelf life. Unlike aviation fuel, auto fuel may have a shelf life anywhere from 90 days to a year from the date of its blending, a great deal of this variable is dependent upon how the fuel is stored. Because aircraft fuel tanks are vented, they are exposed to the atmosphere allowing many of the different compounds within the fuel to evaporate or degrade. As the gasoline ages it will become less volatile making it harder to start the engine, but more importantly, it may lose octane which is our protection against detonation within the engine. This is where the proponents of fuel stabilizers begin their sales pitch. And although we are not against the use of fuel stabilizers, this falls under the category of additives, and we will almost always defer to the engine and airframe manufacturers for suitability. The general rule that seems to have permeated the light sport industry, is that auto fuel has a reliable shelf life of about 30 days. One of the reasons for this relatively conservative number is all the unknown variables that come into play, that you have no control over, primarily what has happened to the fuel between the blending and the time that you pump it into your airplane. Therefore, we typically buy from gas stations that are right on the freeway with relatively high turnover in fuel sales. Buying fuel from a mom-and-pop operation that is not bought a fuel load in six months put you at a distinct disadvantage to start with. Interestingly, the statistics on premium gas is that it is only about 5% of total gas sales. This means that the premium fuel will have been sitting in the ground for considerably longer period than the fuel that comes out of the regular pump. Also, gasoline that is been stored for a considerable period turns into a varnish like substance that coats the internal components of a carburetor. Out of the hundreds of carburetors that we have torn down for troubleshooting, repair, or rebuild, the one universal characteristic seems to be varnish build up that needs to be addressed. If you are using auto gas, and don’t fly often, having a simple, easy, reliable, and safe way to remove fuel from your aircraft and get it into your car is essential. This being said, the best way to remove gas from your airplane is to fly on a regular basis. It is also one of the best things you can do for your aircraft as a preventative maintenance item. And yes, if you need a note for your spouse explaining the necessity for this frequent flying on the basis of “safety”, we would be happy to provide that. In part 1 of this article, we have talked about some of the pros and cons with the use of avgas. And in this article, (part 2) we have addressed the same regarding auto fuel. In the next article (Part 3), we will tie this all together to give you some recommendations on what type of fuel you should be using, and how to mitigate any of the downsides associated with each type of fuel.

Avgas versus Mogas, Part 3, Decision Time

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Life is a series of choices. Most of us are pretty good at choosing between different scenarios. That is right up until the consequences become significant, and all of the choices are less than ideal. One of those choices that still give pilots a lot of angst is this decision between Avgas versus Mogas. In this article, Part 3, we will help you decide how you will approach the dilemma with your aircraft. And when we say dilemma, we are talking about choosing which fuel will be the least detrimental to your particular type of operation. In Part 1 we discussed the downsides of Avgas, and in Part 2 the downsides of Mogas. If you did not get the opportunity, we recommend reading the previous two articles on this subject as a foundation for this article.

The simple decisions first: If the manufacturer of your engine and aircraft recommends not using auto fuel, then the decision is quite simple. The most common reason for this prohibition revolves around the degradation of composite fuel tanks. Over the years we have seen enough problems in this area that we have become “gun shy” to the use of auto fuels in composite fuel tanks. On some aircraft, we have seen degradation of the fuel tank that didn’t show up until years later. Even with fuel tanks that have special sealants applied to the interior of the fuel tank. All of this, simpliy because of a small crack in the sealant allowed the auto fuel to pass the sealant membrane and propagate into the composite structure. In the late 80s, one of our first aircraft builds, was a highly modified Hovey Delta Hawk. One of the modifications was a composite fuel tank that we manufactured to also act as a gap seal between the top two wings. (Figure: 1) Nearly two years after the aircraft’s first flight, the auto fuel had degraded the epoxy in the lower aft right-hand corner of the fuel tank. The fuel tank sprung a leak on a flight from Oroville to Chico, California running out of gas only one mile short of runway 31R, resulting in an off-field landing. The choice to use auto fuel in this aircraft was primarily based on the two-stroke engine that was installed. Which leads us to another

Figure: 1 *Hovey Delta Hawk Built by Brian Carpenter* simple decision when dealing with two-stroke engines.

We have a vast history showing the downsides of using 100LL in two-stroke engines. In our maintenance classes, we have many examples showing the long-term detriment of using 100LL. (Figure: 2) The primary reason for avoiding 100LL is based on the operating principle of the "dykes ring" on the two-stroke pistons. This could easily be an article within itself, but to simplify for now, the buildup of tetraethyl lead within the ring grooves can lead to a rapid decline in ring performance and subsequent failure of the engine. On top of that, the tetraethyl lead is notorious for fouling spark plugs. On the dual ignition two-stroke engines we can get away with 100LL for short periods of time. The fouling of a single spark plug will typically burn clean after a few minutes of normal engine operation on the other spark plug. However, on the single ignition engines (even two-cylinder engines), fouling of a single spark plug will lead to engine stoppage. For this reason, the use of 100LL is considered unacceptable. On the dual ignition 2 stroke engines that have used 100LL for a short period of time, switching back to auto fuel, can, over a period of time, clean out the remnants of the tetraethyl lead, but only if the engine is set up and operating correctly.

Figure: 2 Close-up of Lead build up on a Rotax Piston

Speaking of "set up and operating correctly", all engines can significantly mitigate the effects of 100LL simply by having the engine operating at optimal settings. Having an engine that is running rich, or not burning all the fuel completely, will naturally lead to an increased buildup of tetraethyl lead on not only the combustion side of the engine, but on all of the internal engine components. Complete combustion is one of those events that significantly helps scavenge the carbon and lead buildup from within the combustion chamber. Even with Continental and Lycoming engines we see a significant increase in tetraethyl lead within the oil filters on engines used as training aircraft, primarily because of student pilots who are not trained on how to properly lean the engine during a normal cross-country flight. These aircraft are also the airplanes that require spark plug cleaning on a much more frequent basis.

Back to auto fuel for a bit. The ethanol-based fuels are our biggest concern. If you have the option of buying non-ethanol-based fuel (pure gas), it is most always a better option over the ethanol-based fuels. In Part 2 we discussed in depth the corrosion aspects associated with the ethanol-based fuels. The Rotax 9 series engines are approved for up to 10% ethanol and will operate reliably with this type of fuel. The trick here, is simply to use up the fuel as soon as possible. On aircraft that operate frequently there is little downside to the use of auto fuel. It is primarily the relationship of the potential problems created within the fuel system due to corrosion and fuel degradation that presents a hazard. Using fuel from a station that has high turnover, quality fuel, and used on an airplanes that operates at least 10 hours a week is probably the ideal operating condition. Letting the fuel sit for weeks on end is where we start to see the majority of problems. For aircraft that fly in the neighborhood of, less than 10 hours per month, we start to favor the use of 100LL simply because the trade-off in potential maintenance problems related to the older auto fuel. If the airplane is going to fly, we would like to use auto fuel. If the airplanes going to sit, we would like to use 100LL. This now brings up an alternative operating procedure. If it’s the summertime, and you have plans to fly on a very frequent basis, go ahead and use auto fuel. As it gets closer to winter or to a time period where you know you’re not going to be operating the aircraft, start switching over to 100LL. If you had anticipated flying and were loaded with auto fuel, and then ended up not flying, we just recommend having a method where you can easily get the fuel out of your airplane and put it in your other vehicles. If your airplane has sat for a period of time with an ethanol-based fuel, we would recommend an inspection before getting back into the air. At a minimum, pull the float bowl off the carburetors to see the internal condition. Old degraded fuel, or corrosion would be a red flag to dig in even further. Remember, the degradation caused by fuel not only affects the carburetor but all the rest of the fuel system. The fuel pump, fuel lines, fuel selector valves, and the fuel tanks. A degraded carburetor float bowl is only a symptom of a much larger problem. For those that are unsure of how much flying they might do in the near future, we would probably just recommend 100LL.

That leads us to our latest ex-

Figure: 3 Rans S-6S Coyote II Right and Left Fuel Tanks periment that we are doing at Rainbow Aviation. We have a Rans S-6 Coyote (Figure: 3) that we have modified to allow the use of 100LL in one fuel tank, and auto fuel in the other fuel tank. This allows us to operate primarily on auto fuel during the majority of a flight. Once we are -10 to 15 minutes from our destination, we can simply switch to the 100LL. This leaves the aircraft sitting in a condition as though it had always run on 100LL with none of the downsides of letting auto fuel sit inside of the fuel system. But because we are operating for such a short period of time with the 100LL it significantly reduces the negative effects of tetraethyl lead within the engine. Although not our primary thought process. It does allow us to mitigate the potential effects of auto fuel that starts to degrade with time. Old auto fuel under extreme conditions may not be up to the task. But by using 100LL for takeoff, climb, and landing, we essentially have the safety and reliability of the 100LL, and eliminate the possible problems associated with old auto fuel. Once at altitude, where the manifold pressure is lower and the potential for detonation reduced, we can switch to the auto fuel. This can significantly reduce the operating cost, and if at any point we suspect the auto fuel is compromised, we can always switch back to the 100LL for safety. Having the reliability of 100LL for the takeoff and landing phase of flight along with the long-term storage benefits struck us as a concept worth experimenting with. And let it be said, that this is, in fact, an experiment. Often, we don’t recognize the downsides until we have put enough time in to be confident of our hypotheses. We will continue to evaluate our concept and publish the results.

Last but not least, we need to address the issue of Swift fuels (UL94). It is nearly impossible for us to make any legitimate comments about Swift fuels when we have literally no experience. Our research into what Swift fuels is doing is very positive and we would probably be using it if we had access. For you Midwesterners, there is a lot of options available. However, for us on the West Coast, the San Carlos airport is the only airport from Mexico to Canada that actually supplies the UL94 fuel. And there are only four other private operators west of Kansas that utilize the UL94.

Everyone’s availability to different types of fuel is different and along with the different mission profiles makes a one-size-fits-all approach inadequate. However, with the different concepts and underlying theories presented in these three articles, you should now be able to make a better-informed decision about how best to approach your particular operating circumstances depending on fuel availability and your unique mission profile.

Aviation Maintenance:
Symptoms Versus Problems

In forty plus years of aircraft maintenance there is one outstanding theme that still continues to bludgeon our psyche to this very day. The vast majority of maintenance related problems and accidents are not a cause of lack of information, wear, age, or poor design - but rather, by human error. The majority of aircraft maintenance related problems and accidents are actually caused by the owner/operators. Identifying, repairing and preventing maintenance related problems is one of the greatest challenges, but not for the reasons that you might think. One of the best insights that students from our maintenance classes receive is the recognition of the difference between symptom and problem. Identifying the difference between a symptom and a problem is critical when conducting maintenance on aircraft. In this article, we will use the term “problems” for the root cause of a problem or maintenance discrepancy. On the other hand, “symptoms” by definition means “something that indicates the existence of something else”.

To get us started we will use a recent example. The owner of a new SLSA airplane with a new continental O-200 engine arrives at the shop with a total of 49 hours on his new aircraft. Within the first 10 hours of operation of the aircraft, the owner had identified the symptom of oil leaking from the Garlock seal around the starter driveshaft. (Symptom). The amount of oil that was leaking was significant and was covering the belly of the aircraft as well as the windshield. Solution: owner replaces the brand-new continental starter with another brand-new continental starter. Results: within hours of installing the new starter the oil was once again leaking profusely from the starter Garlock seal duplicating the original (symptoms). Solution: owner replaces the second brand-new continental starter with an after-market Sky-tech starter. Results: oil continues to leak at a slightly slower rate, (symptom). Solution: live with the problem. Ironically, we only became involved with this scenario as a result of the owner bringing the aircraft to us to solve an additional problem of radio noise. In the process of identifying the radio noise, we identified the Sky-tech starter as an anomaly on what should have been a stock SLSA airplane. A conversation ensued that uncovered this series of interactions between the aircraft owner and his aircraft. We explained that it is virtually impossible for the continental starter to fail the Garlock seal under normal conditions. After a brief lecture on the possible root causes of this particular symptom, we were able to explain to him that this symptom is normally a result of over pressurization of the crankcase. Over pressurization the crankcase is typically a result of low compressions and blow-by around the rings into the crankcase. A quick test by pulling the propeller through by hand confirmed this as at least a likely scenario. Unbelieving that this was even possible on a 49-hour new engine, the owner requested an official compression check which revealed that indeed, none of the four cylinders reaching even a pathetic 40/80. After explaining to the owner that this was probably a result of an improper engine break-in, he revealed that the aircraft manufacturer had told him that the engines come from the factory already broken in. And his explanation of his flight from the east coast to the west coast immediately upon receipt of the aircraft at a constant RPM, in cruise, was the confirmation that the improper break-in and subsequent glazing of the cylinders as the root cause of the problem. We can continue to change starters “until the cows come home” but it’s not going to improve the compression. Without the significant and costly intervention to repair the cylinders the engine remains in a state of significant compromise. Think of all of the dangers associated with fixing the symptoms rather than the problem. For example, we are flying around with significantly reduced power output - dangerous at best. We are going to have significant oil fouling of spark plugs, and the potential for loss of additional power should both spark plugs be fouled on a single cylinder.

Talking with the owner it was easy to identify the reason that he had chosen to fix symptoms rather than the problem. Having basically no understanding of the engine systems in particular, and maintenance in general, left him with no tools from which to even begin to approach solving the root cause of the problem. This is the primary reason that everyone is reluctant to address root cause problems. In order to address a root cause problem, you have to be able to identify all of the probable sources contributing to the problem. The amount of education necessary to become intimately familiar with the aircraft and engine systems can be quite intimidating. Taking the aircraft to a professional who is intimately familiar with the aircraft and engine systems can, often times, be quite expensive.

The result is a tendency to focus in on symptoms rather than root cause problems. Symptoms, are easy to identify, simple, and usually are much easier to make disappear. The problem with fixing a symptom is two-fold. The first issue is that by treating the symptom you are not actually curing the problem. The second issue is that by making the symptom disappear you are covering up the one, and often only, telltale sign that there actually is a problem. Symptoms can be inexpensive to identify, repair, and make disappear. However, it is the equivalent to solving the problem of the blinking check engine light, flashing away, as a result of lack of oil in your car engine, by unplugging the check engine light. Recognize that symptoms are one of the most valuable resources that you have in troubleshooting the root cause of any problem. By eliminating symptoms, you are eliminating all of the information that you need in order to be able to troubleshoot what is really going on.

Aircraft owners are often shocked by our explanation of how we troubleshoot an aircraft/engine problem. It’s really quite simple. And even though it’s simple, it can sometimes be rather expensive and time-consuming. The process involves bringing the aircraft into the shop, taking all of the owner’s observations and experiences with the aircraft into account, and then identifying all of the subsystems that may have any correlation with symptoms. Once we have identified all of the subsystems that may have some correlation with the root cause of the problem, we do an inspection on each one of those subsystems. Then the process of repairing discrepancies found within each of those subsystems begins. All we are essentially doing is returning the aircraft and engine back to its original stock configuration. When we are done, we simply run the engine to verify that everything is working correctly. It works every single time without many exceptions. How is it possible that this would not work? Especially with the consumer engines like Lycoming, Continental, and Rotax that have been proven and in service for many decades. If you put the engine back into the configuration as it was when it came out of the factory, it's going to work correctly. If it does not work correctly, this is simply an indication that something was missed on your initial inspection and the engine is not in the stock configuration.

Now even though we have identified how simple it is to troubleshoot a problem, this is where the system breaks down. In order to be able to troubleshoot the root cause of a problem you have to have a complete and comprehensive knowledge of all systems. Having a partial understanding of the system generally leads to assumptions that are not only wrong, but can actually cause additional problems. Customers are often frustrated about our unwillingness to troubleshoot problems over the phone. The reason for this, is that what they are really asking, is for us to troubleshoot symptoms. "Fixing Symptoms Causes Problems". We are often horrified at what we see on Internet chat rooms. It seems that the vast majority of the forum discussions are based on the premise of dealing with symptoms rather than problems. On occasion, we see the valiant heroes attempting a twenty paragraph dissertation on the subject trying, in vain, to sort out the misinformation that is so prevalent.

You don't have to wait for symptoms to show up to start solving the problems. When you find something that is broken, worn, out of adjustment, corroded, or just improperly installed, it is time to fix that "problem". It is all too common that we have a customer with an airplane who believes that maintenance is part of the annual inspection. Nothing could be further from the truth. A proper annual inspection should be nothing more than a verification that the maintenance which has been accomplished during the year has been done correctly and that there are no anomalies which should be addressed. Those customers who maintain their aircraft on a regular basis and fix everything immediately upon identification, find that the overall cost of maintenance on their aircraft is reduced and their reliability increased. Waiting for a symptom, "that scares the hell out of us", before bringing the aircraft into the shop for repairs is not a very efficient way to approach maintenance. An airplane that is maintained in top-notch condition becomes very easy to troubleshoot should a problem arise. An airplane that has a plethora of deferred maintenance becomes very difficult to troubleshoot primarily because of the numerous deficiencies that may be contributing to the problem. It's not uncommon we find one problem causing several other problems, which are in turn causing several other problems. These can be very difficult customers to work with because properly solving all of the contributing problems can sometimes be time-consuming and costly. They don't necessarily want to spend the money, they simply want the airplane to stop scaring them. It simply doesn't work that way. The mechanics willing to fix only the symptoms that have been scaring the aircraft owner often find themselves in trouble when months later the root cause of the problem rears its ugly head.

If there's one bit of practical advice that we can give to any aircraft owner - it is to become intimately familiar with all of your aircraft and engine subsystems. Actually, being in aircraft builder is one of the best ways to become familiar with aircraft and engine sub-systems. If you're not there yet, find yourself a resource who can support you while you are learning. If you were to ask us advice about how to become a better pilot, we would put becoming better informed about your aircraft and engine right at the top of the list.

Bending Sheet Metal

RAINBOW Aviation Services™

We are often surprised by the number of aircraft builders who seem to be intimidated by the process of calculating bend allowance, setback, and simply creating a flat layout for bending a simple part. In this article we are going to back up a bit, and provide some of the theory necessary to understanding how we go about the process of converting a flat piece of sheet metal into a complex sheet metal component. Learning to accurately layout and bend sheet-metal is a very useful exercise. Once you have mastered the process, you will find that it not only saves a great deal of time, but also can save you a great deal of wasted material.

To start with, let's examine some of the properties of aluminum sheet metal used in aircraft. The two most common alloys of aluminum used in the experimental aircraft world are, 6061 T6, and 2024 T-3. 6061 is one of the least expensive and most versatile of the heat-treatable aluminum alloys. 6061 T6 has a tensile strength of approximately 40,000 psi. It has good corrosion resistance in comparison to 2024 T-3. And current cost per square foot of .040" is $2.53. On the other hand, 2024 is one of the best known of the high strength aluminum alloys. With its high strength, about 50,000 psi tensile strength in the T-3 condition, it is used on structures and parts where good strength-to-weight ratio is desired. Since corrosion resistance is relatively low, 2024 is commonly used in clad form ("Alclad") with a thin surface layer of high purity aluminum. The cost of 2024 T-3 is about 50% more than 6061 T6 aluminum, costing about $3.94 per square foot for .040" sheet.

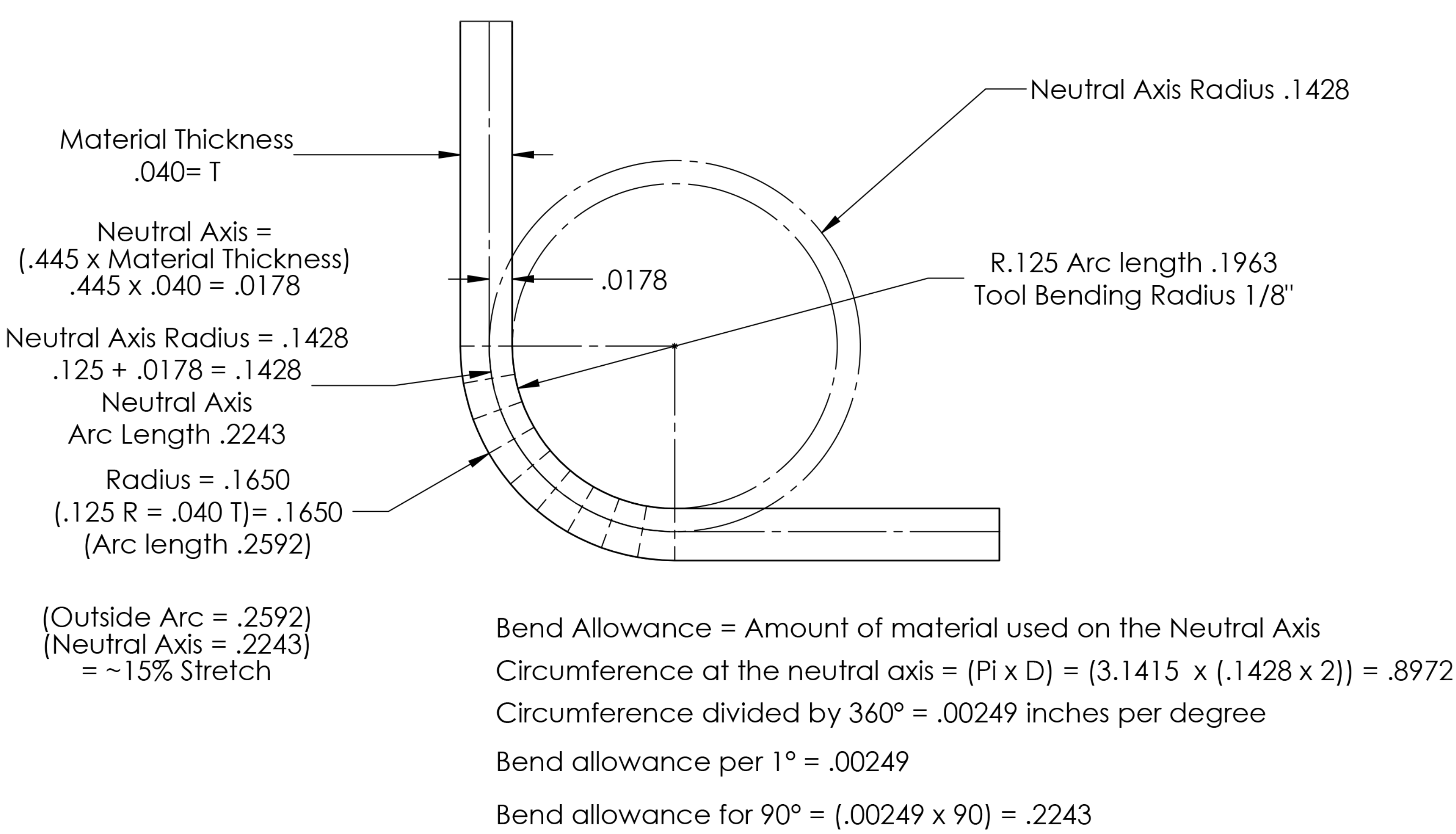

Figure: 1 Bending Aluminum

Understanding the properties of each of the aluminum alloys becomes very important during the sheet-metal layout and bending process. In particular, the malleability and ductility. By definition, ductility is a solid material's ability to deform under tensile stress. And malleability is a material's ability to deform under compressive stress. The ductility of 2024 T-3 is about 18%. When bending aluminum around a radius, we can see that we are both stretching one side of the aluminum (ductility), and compressing the other side of the aluminum, (malleability). (Figure: 1). Extensive testing has shown that the "neutral axis" (neither, under compression or tension) during the bending process is about .445 times the thickness of the material. The smaller the radius that the metal is bent around, the greater the differential between the neutral axis and the outside arc of the skin. Additionally, the greater the thickness of material, the greater the differential between the neutral axis and the outside arc of the skin. Stretching the outer skin beyond its limits will normally result in cracking. Of course, there isn't a necessity for calculating the minimum bend radius because most sheet-metal manuals, including AC 43.13-1B, have a minimum bend radius chart available for quick reference. (Figure: 2)

Minimum Bend Radius		
Material Thickness	6061-T6	2024-T3
0.020	1/16	1/16
0.025	1/16	1/16
0.032	1/16	3/32
0.040	3/32	3/32
0.050	3/32	1/8
0.063	1/8	5/32
0.080	3/16	1/4

Figure: 2 *Sample Bend Radius Chart*

The tool, which we use for bending sheet-metal, is called a "brake". A sheet-metal brake used for aircraft aluminum has either fixed or interchangeable jaws with a very specific radius built into the jaws. In our shop, we use a 1/8 inch radius which allows us to bend up to .063" 6061 T6 aluminum. This allows us the ability to bend the majority of sheet metal sizes used in small experimental aircraft. Understanding the necessity for utilizing a radius during the bending process will, now, help us to understand how to calculate bend allowance. Bend allowance is nothing more than the amount of material that is used for the bent portion of the sheet-metal. The radius of the bend at the neutral axis is the tooling radius + (.445 times the thickness of the sheet metal). Multiplying the radius times 2 will give us the diameter, and multiply that times pi (3.1415) will give us the circumference. Taking the circumference and dividing by 360° will leave us with a dimension per 1° degree of bend. Multiplying that times 90° will give us the bend allowance for a 90° bend. (Figure: 1) Although the process of calculating bend allowance is relatively simple, it's made even easier by the use of a bend allowance table. A bend allowance table has a matrix of the most common sheet-metal sizes and the standard bending radii already calculated for both a 1° bend as well as the most common, 90° bend. A bend allowance table can be found in Advisory Circular 43.13-1B. When we prepare a piece of metal for bending, we are doing what we call a flat layout. All sheet metal components are simply a series of flat sections and bends. Prior to bending up a sheet-metal part we get out a piece of scratch paper and simply formulate a layout similar to what we see in (Figure: 3). We will lay out each flat section with the bend allowance required for each of the bends. In this case, because the bends are all 90°, the material thickness is the same, and the radius for each of the bends are also the same, we only need to calculate or look up bend allowance once. The amount of material (bend allowance) used for each of the bends is identical. Next we simply need to calculate the length of each one of the flat sections. The normal formula for calculating the flat section is given dimension, minus setback. "Setback" by definition is the radius plus the thickness used during the bend. If all given dimensions were given from the outside of the

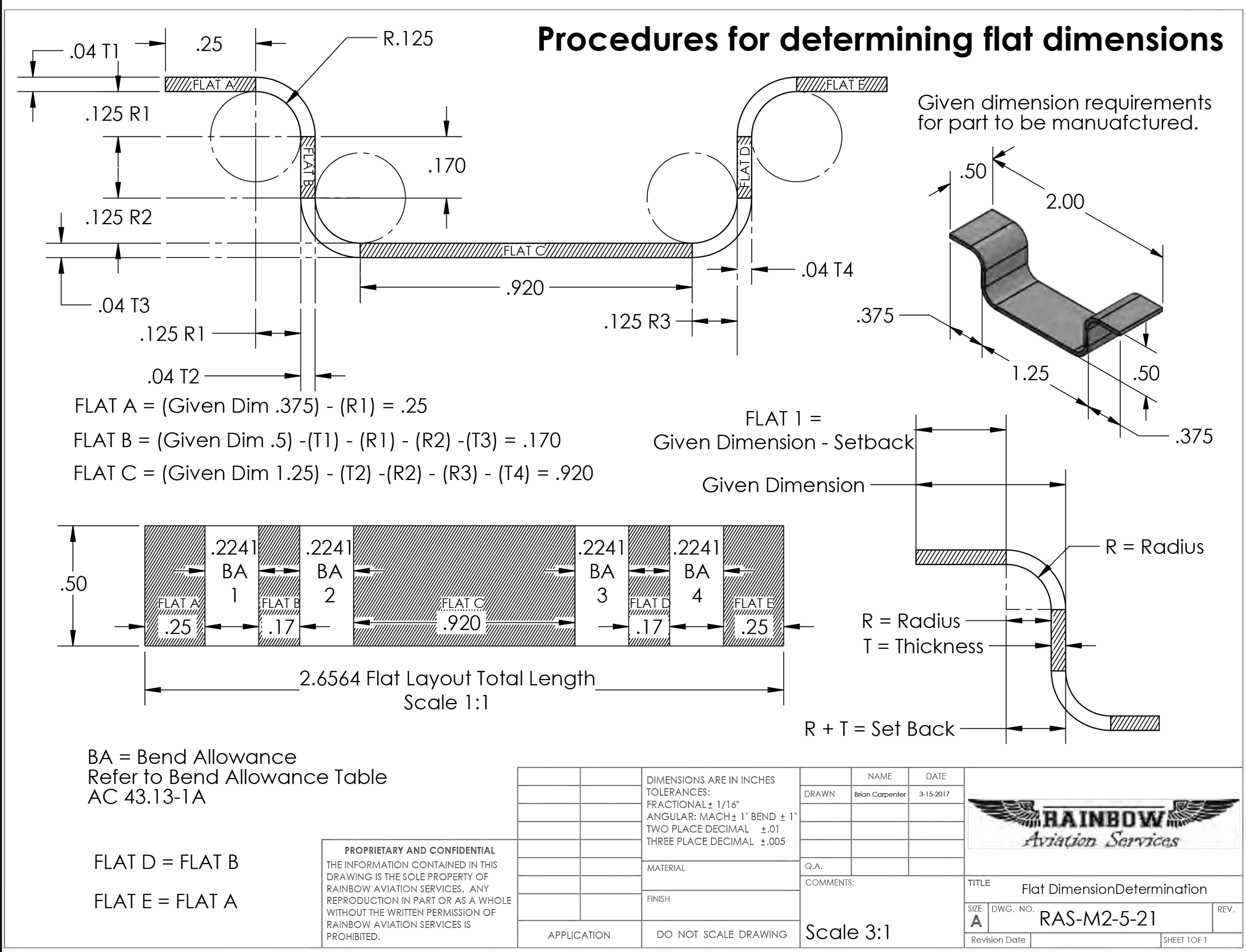

Figure: 3 Procedures For Determining Flat Layout

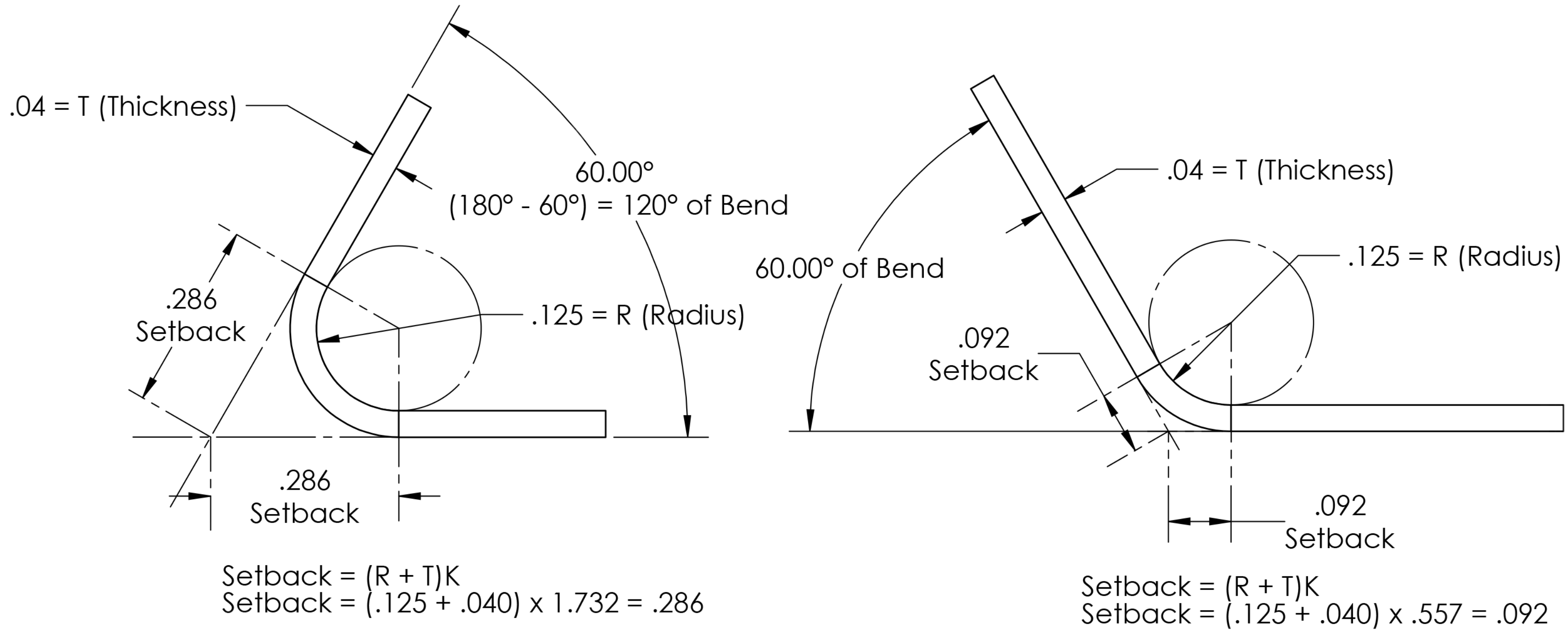

Figure: 4 Calculating Setback for Acute and Obtuse Angles

material to the end of the flat section this formula would work great. However there are many cases where you're going to have to extrapolate on this formula in order to calculate the flat section length. For example, in order to calculate the length of FLAT A, the given dimension is from the inside of the bend. In this case FLAT A = (given dimension .375) - (bend radius .125) = .25. In order to keep comprehension to a higher level, we normally start by teaching bend allowance as we have shown here, with all bends being conducted at 90°. Once we have mastered the process calculating for 90° bends, we can now venture into the calculations necessary for bends that are more acute or obtuse. (Figure: 4) We still use setback which is radius + thickness however this time we multiply a K factor. A K factor chart is available in Advisory Circular 43.13-1B (Figure: 5). This is simply another complex mathematical calculation distilled into a matrix which correlates to the correction factor to the angle of the bend. To calculate the length of each flat, use the same procedures as we used in calculating for a 90° bend. Simply take the given dimension and subtract the setback. When calculating the bend allowance for the bends that are other than 90° simply multiply the bend allowance for 1° times the number of degrees that the metal is bent. This is the same number of degrees used when calculating setback utilizing K factor.

You may have become very proficient at bending aluminum using the old standby method where you start with an extra-large sheet, bend it to the appropriate angle, then cut off the excess material to come up with your final dimension. There's nothing particularly wrong with utilizing this method, however if you have more than one bend you're going to be in big trouble. This is where I see individuals getting fairly creative-by guessing at the dimensions, bending the metal, and re-measuring to see how far off they are. Then changing their original dimensions by the amount of error in the original part and re-bending a new piece. After about three or four tries, they can typically get pretty close. But as you might imagine, this can be quite time-consuming, expensive, and frustrating. If you find yourself working on aluminum aircraft on a regular basis, the amount of effort required to learn to do sheet-metal layout is really

Deg.	K	Deg.	K	Deg.	K	Deg.	K	Deg:	K
1	0.0087	37	0.3346	73	0.7399	109	1.401	145	3.171
2	0.0174	38	0.3443	74	0.7535	110	1,428	146	3.270
3	0.0261	39	0.3541	75	0.7673	111	1.455	147	3.375
4	0.0349	40	0.3639	76	0.7812	112	1.482	148	3.487
5	0.0436	41	0.3738	77	0.7954	113	1.510	149	3.605
6	0.0524	42	0.3838	78	0.8097	114	1.539	150	3.732
7	0.0611	43	0.3939	79	0.8243	115	1.569	151	3.866
8	0.0699	44	0.4040	80	0.8391	116	1.600	152	4.010
9	0.0787	45	0.4142	81	0.8540	117	1.631	153	4.165
10	0.0874	46	0.4244	82	0.8692	118	1.664	154	4.331
11	0.0963	47	0.4348	83	0.8847	119	1.697	155	4.510
12	0.1051	48	0.4452	84	0.9004	120	1.732	156	4.704
13	0.1139	49	0.4557	85	0.9163	121	1.767	157	4.915
14	0.1228	50	0.4663	86	0.9324	122	1.804	158	5.144
15	0.1316	51	0.4769	87	0.9489	123	1.841	159	5.399
16	0.1405	52	0.4877	88	0.9656	124	1.880	160	5.671
17	0.1494	53	0.4985	89	0.9827	125	1.921	161	5.975
18	0.1583	54	0.5095	90	1.000	126	1.962	162	6.313
19	0.1673	55	0.5205	91	1.017	127	2.005	163	6.691
20	0.1763	56	0.5317	92	1.035	128	2.050	164	7.115
21	0.1853	57	0.5429	93	1.053	129	2.096	165	7.595
22	0.1943	58	0.5543	94	1.072	130	2.144	166	8.144
23	0.2034	59	0.5657	95	1.091	131	2.194	167	8.776
24	0.2125	60	0.5773	96	1.110	132	2.246	168	9.514
25	0.2216	61	0.5890	97	1-130	133	2.299	169	10.38
26	0.2308	62	0.6008	98	1.150	134	2.355	170	11.43
27	0.2400	63	0.6128	99	1.170	135	2.414	171	12.70
28	0.2493	64	0.6248	100	1.191	136	2.475	172	14.30
29	0.2586	65	0.6370	101	1.213	137	2.538	173	16.35
30	0.2679	66	0.6494	102	1.234	138	2.605	174	19.08
31	0.2773	67	0.6618	103	1.257	139	2.674	175	22.90
32	0.2867	68	0.6745	104	1.279	140	2.747	176	26.63
33	0.2962	69	0.6872	105	1.303	141	2.823	177	38.18
34	0.3057	70	0.7002	106	1.327	142	2.904	178	57.29
35	0.3153	71	0.7132	107	1.351	143	2.988	179	114.59
36	0.3249	72	0.7265	108	1.376	144	3.077	180	Inf.

Figure: 5 K Factor Chart for Determining Setback

quite minimal. Once you’ve practiced a bit, you can develop confidence and accuracy worthy of a professional. It’s very rewarding to go through the process of laying out a fairly complex part with multiple bends and have it fit into the aircraft on the first shot. In part 2 of this article, we will address some of the more practical aspects of bending aluminum such as how to place the metal into and set up the sheet-metal “brake”. Establishing a site line. And some other tips and tricks that will get you on your way to becoming a sheet-metal whiz.

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Bending Sheet Metal (Part 2)

RAINBOW Aviation Services™

In part one of this article we discussed, in depth, the theory and the process for developing a flat layout for manufacturing a sheet-metal part. In this article, we will take it to the next step: the practical process of converting the flat layout to a bent sheet-metal part. The tool that we use for bending sheet-metal is called a "brake." There are several different types of brakes. A "press brake", commonly found in manufacturing environments, uses a vertical positioned die bending the sheet-metal over a stationary "V" block. A "cornice" brake, which has a solid clamping bar the full width of the brake, is limited to simple straight bends. And the "box and pan" brake. The box and pan brake is sometimes referred to as a finger brake because of its individual fingers which can be configured in a nearly unlimited fashion to make some of the most complex sheet-metal parts. If you are interested in purchasing a sheet-metal brake for building experimental aircraft, this would most likely be your first choice.(Figure: 1) In our shop we use a box and pan brake manufactured by Mittler Brothers. It has a very unique combination of individual bed fingers as well as leaf fingers and a complete selection of radius fingers from 1/16 inch to 5/16 inch radius. In part 1 of this article we talked about the necessity for bending aluminum around a radius and paying particular attention to the minimum bend radius. The amount of force required to bend sheet-metal tightly around a radius can be quite substantial. As the sheet-metal gets thicker, the amount of force required increases substantially. Normally the brake is rated for the maximum gauge material that the

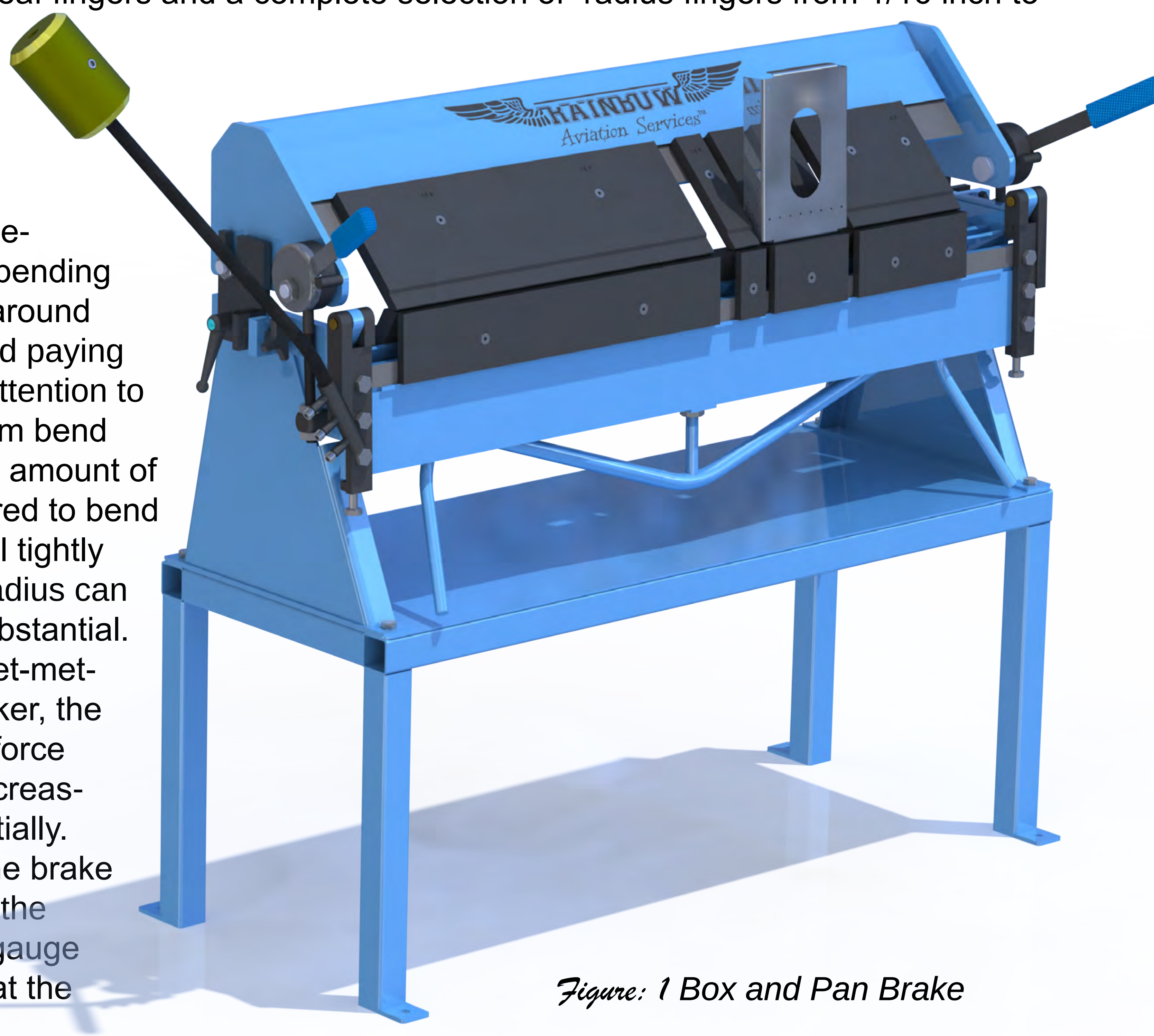

Figure: 1 Box and Pan Brake

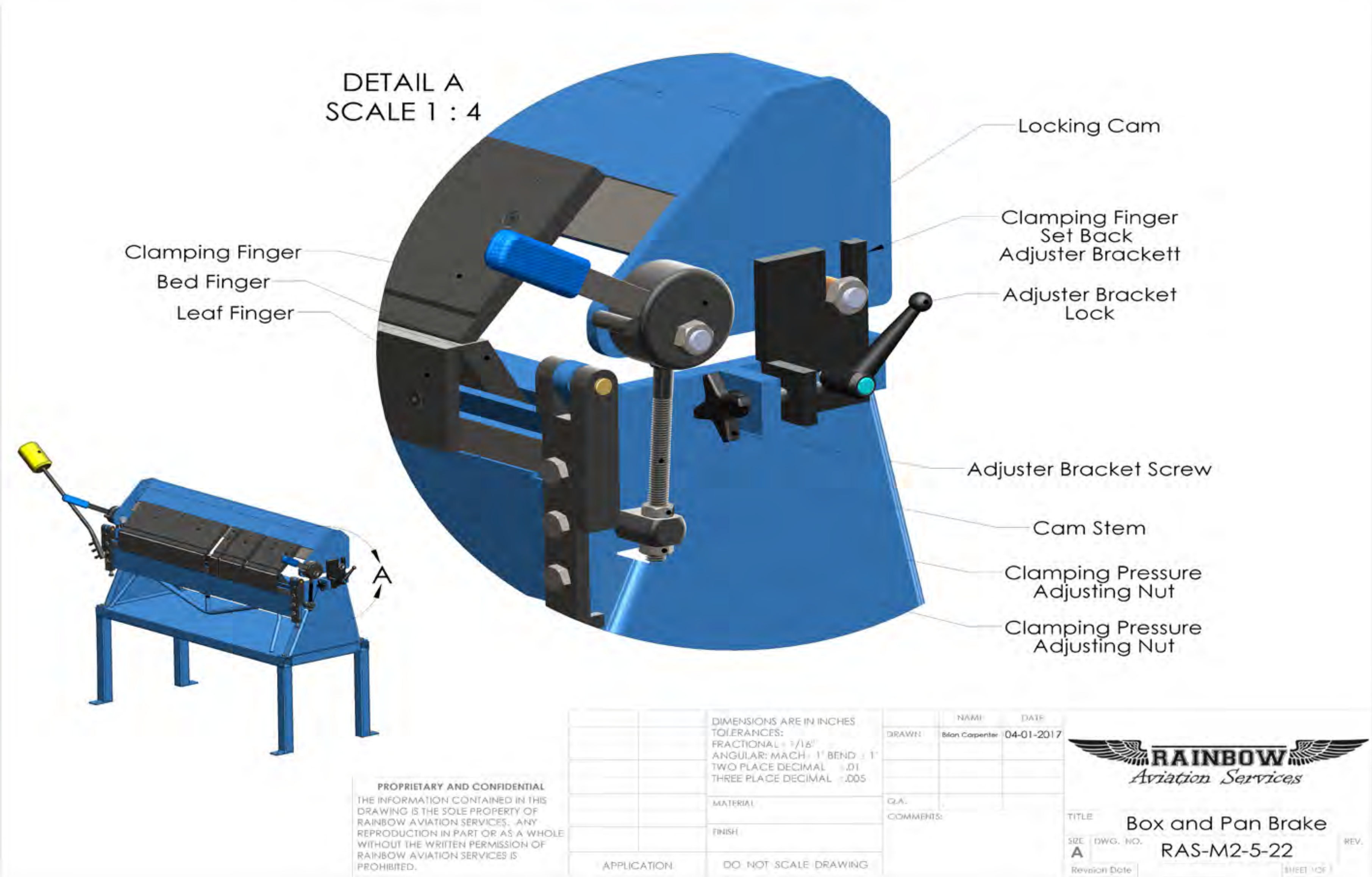

Figure: 2 Box and Pan Brake Adjustments

machine is capable of bending. This requires that you select a brake compatible with the thickness of material that you are bending. For example, a 16 gauge brake is capable of bending 16 gauge (.062”) mild steel. And a 22 gauge brake is capable of bending 22 gauge (.030) mild steel. Even though the standard for gauging brake capacity is using mild steel, we can get away with bending a little bit thicker material when bending aluminum. A 16 gauge brake could typically bend up to (.080”) aluminum and a 22 gauge break could bend up to (.040”) aluminum. You may be able to bend thicker material than the break is rated for, however, it is possible to do permanent damage to the brake if you exceed its limitations. Keep in mind that a high quality sheet-metal brake is a precision tool. Keeping it in good working order and properly adjusted will allow you to make precision bends consistently. Fortunately, most of the small experimental aircraft use sheet-metal thicknesses that are relatively small. Typically .016” to .063”. As a result, some 15 years ago we elected to purchase a 16 gauge box and pan brake that continues to serve us well on a daily basis. If you’re interested in purchasing a brake, selection of the gauge rating is only one of the criteria. You also must choose the width of the brake, which will determine how long of a piece of sheet-metal you can bend. And as you might imagine, both gauge and length significantly increase the cost. We have found that a high quality 48 inch box and pan brake is probably the biggest bang for the buck. In addition, it’s easy to move and doesn’t take up a lot of space.

Before we can begin using the break, it’s necessary to make sure that we have it properly adjusted. Trying to make precision bends without first setting up the brake can become very frustrating. Remember, it is a precision tool. The adjusting mechanisms are located on each end of the brake. There are two adjustments that will be necessary any time that you change material thickness. Clamping pressure, and clamping finger setback. At first glance you may think that this seems a bit cumbersome just to bend a piece of sheet metal, but I assure you, once you've done it a few times it really is quite simple. To start with, clamping pressure should be only enough to keep the material from slipping during a bend. One of the biggest, and most common, mistakes made is the use of excessive clamping pressure. Excessive pressure can cause the clamping fingers to shift forward, leaving inadequate space for the aluminum during the bend. Clamping pressure can be adjusted by the two nuts located on the stem of the locking cam.(Figure: 2) By adjusting the nuts up or down the clamping pressure can be increased or decreased. Keep in mind that all adjustments need to be accomplished on both ends of the brake. Typically, we stick small sample pieces of the material, that were about to bend, 2 to 3 inches from each end of the brake. While engaging and disengaging the locking cam, we will make adjustments to the adjusting nuts until we have just the right amount of tension on the sheet-metal. Next, we will need to adjust the clamping finger setback. The purpose for this is to provide enough space between the bending leaf finger and the nose of the clamping finger at the point of maximum bend. If not enough space is provided at the maximum point of bending, damage to the aluminum or the radius fingers is possible. Think about this: If you are applying 50 pounds of force on the 15 inch handle, the bending leaf that is making contact with the

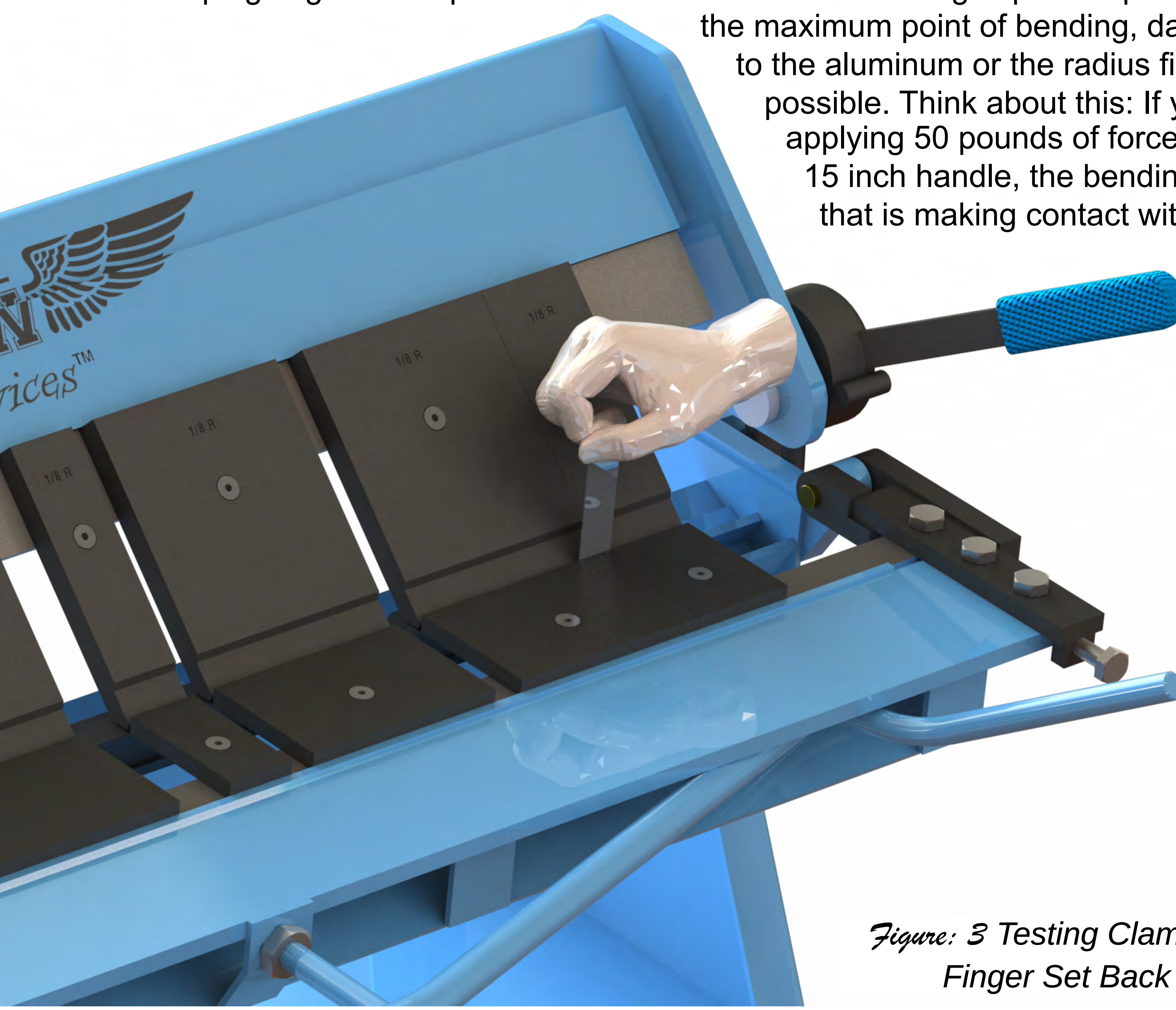

Figure: 3 Testing Clamping Finger Set Back

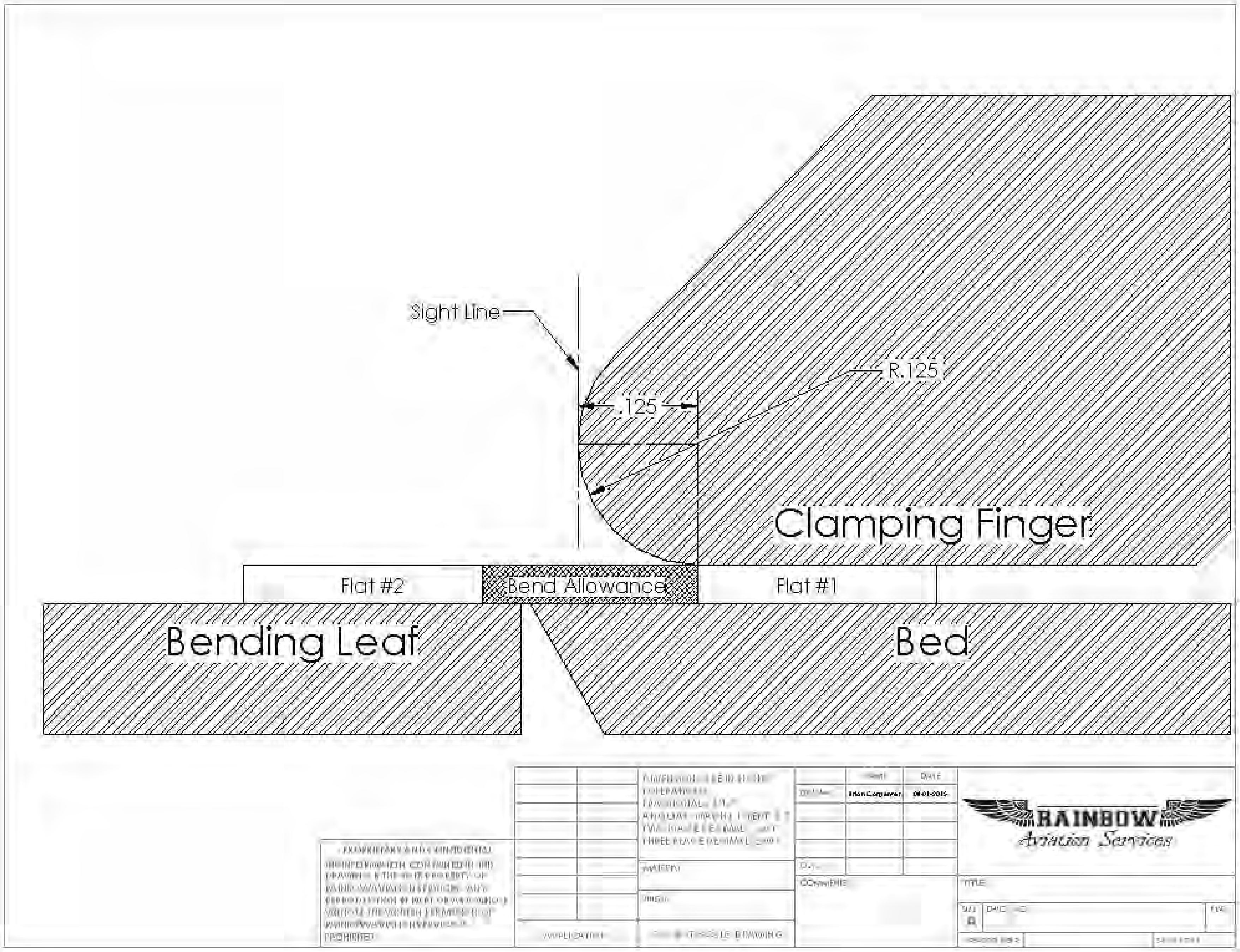

Figure: 5 Using a Sight Line to Position the Flat Layout for Bending

sheet-metal, 1/4" away from the bending axis, is applying 3000 pounds of force to the sheet-metal and clamping finger. The whole purpose of the sheet-metal brake is to take advantage of this leverage. With the counterbalance weight installed, the amount of force required to bend a piece of sheet metal is really quite small. If you find yourself applying an inordinate amount of pressure during the bend, it probably means that you have it mis-adjusted. Don't force it! Adjusting the clamping finger set-back is quite simple. Move the bending leaf to the angle that you will be bending, typically 90°, and insert your sample piece of aluminum used to check clamping pressure in between the radius of the clamping finger and the bending leaf.(Figure: 3) We then simply release the locking clamp and rotate the adjusting screw knob in or out until we have approximately 1.5 times the thickness of the material between the clamping finger and bending leaf. Having excessive space will typically result in a larger radius than the radius of the bending finger. This of course, will throw off all of your bending calculations, and subsequently the final dimensions of your bent component. Once we have adjusted the finger setback on both sides of the brake, we will reengage the bracket locks and we are now ready to begin bending our piece of sheet metal.

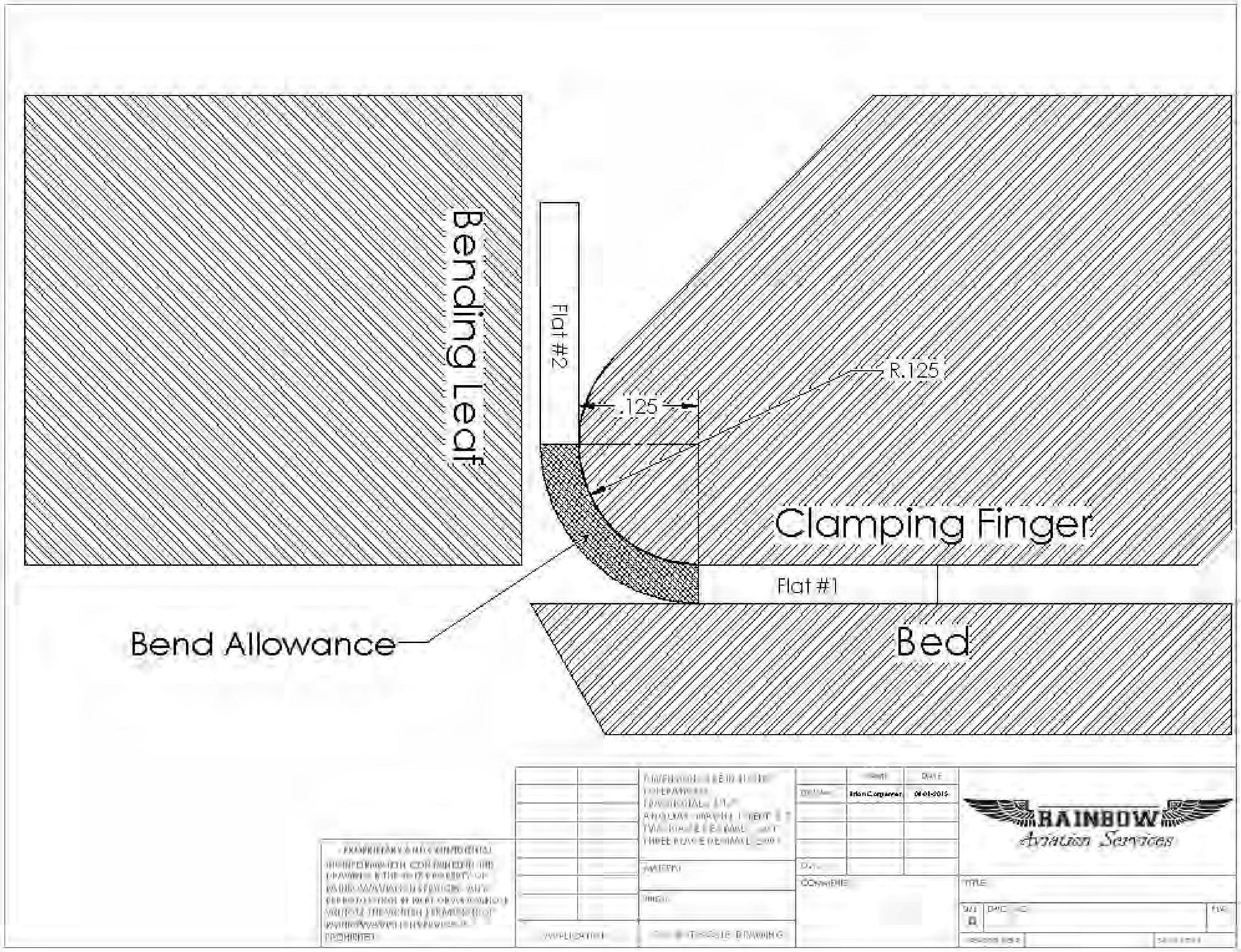

Figure: 6 Bent Material

Positioning the flat layout for bending can seem daunting at first, but once you understand the basic premise, you will be saying to yourself, “why didn’t I think of that”. In part one of this article we created a flat layout that consisted of flats and bend allowance. The bend allowance, and hopefully “only” the bend allowance, is the section of the metal that we will be bending in the finger brake. The bend will begin at precisely the end of the flat section and continue bending to precisely the beginning of the next flat section. The trick here, is how do we position the flat layout so that the beginning of the bend allowance starts at exactly the bottom of the radius finger. Keep in mind this is the section that is underneath the clamping finger. Once clamped in place, we are unable to see at least half of the bend allowance section of the sheet-metal. So how do we precisely locate the mark on the sheet-metal that denotes the beginning of our bend when we can’t see it? The trick is, move the mark to where we can see it. We call this, the “site line”.(Figure: 4) One of the known variables is the radius of the clamping finger. The distance from the bending axis to the leading edge of the radius finger, in our case, is 1/8”. By placing a site line on the flat layout that is projected 1/8” from the edge of the bend allowance that will be under the brake, we now have a site line that we can use as a positioning reference. By looking straight down from above the brake, we can align the leading edge of the radius finger with the site line while clamping the flat layout in position. By default, this positions the beginning of the bend allowance at exactly the beginning of the radius on the clamping finger. Although it may appear close in some circumstances, the site line is not the center of the bend allowance. As a result, if you create a site line and then inadvertently position the layout 180° from your intended position, this will completely reposition the bend allowance and your final product will be long on one flat section and short on the other. On parts containing multiple bends, you may find it more convenient to place the site line onto your layout after you decide which orientation is necessary. This will allow you to check for interference between the bent legs and the clamping fingers. In our maintenance classes the students have a contest to see how close they can bend their part to the drawing dimensions of a sheet-metal project. The students that perfect this technique can bend their parts to within .010" of the final dimensions. Working with sheet-metal has always been considered an art rather than a trade. And like any artistic endeavor, building a sheet metal airplane, a component, or even doing a repair can be both satisfying and rewarding. And like any artist, having the right tools and knowing how to use them is the secret to making the canvas come alive.

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Propeller balancing is an integral part of building, operating, and maintaining an experimental aircraft. A properly balance propeller is a propeller that has the center of mass co-located with the rotational axis of the propeller and prop shaft. The most common and easily accomplished methods of balancing a propeller is using one of many static balance tools. The ($30) “Buzz Master” prop balancer (Figure: 1) is an example of a low cost and simple tool that is considered a must have for those aircraft that have a propeller with a 1-inch diameter center hole (Figure: 2). Using a string, a centering slug, and a simple bubble level allows you to get extremely accurate “static” balance results. This static balancing is capable ensuring that the propeller is within balance. However, what it does not consider, is any engine, spinner, spinner-bulkhead, and mounting hardware differences that may cause an engine to vibrate even after installing a propeller that has been perfectly balanced. And although the price tag for a “dynamic” propeller balancer can run into the thousands of dollars, addressing all the aforementioned components as well as the engine and propeller is where the dynamic prop balancer really shows its colors. For several years now, we have been utilizing a Dyna-Vibe GX3 dynamic prop balancer. This utilizes an accelerometer and an optical tach (mounted to the engine) to measure vibrations not only in amplitude, but in relationship to the “master blade”. On a typical direct drive engine like a Continental, Lycoming, or Jabiru engine, the GX3 will spit out a polar report (Figure: 3) showing the magnitude and location of the imbalance.

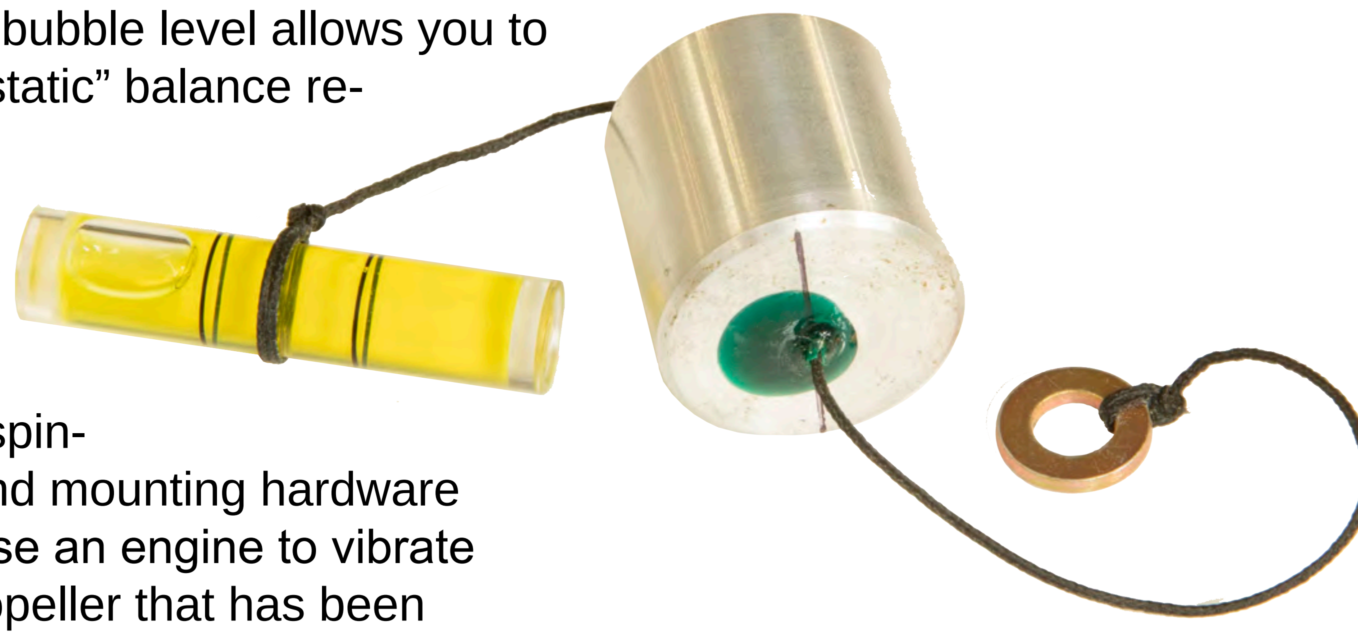

Figure: 1 Buss Master Prop Balancer

Figure: 2 Buss Master Balancer in Action

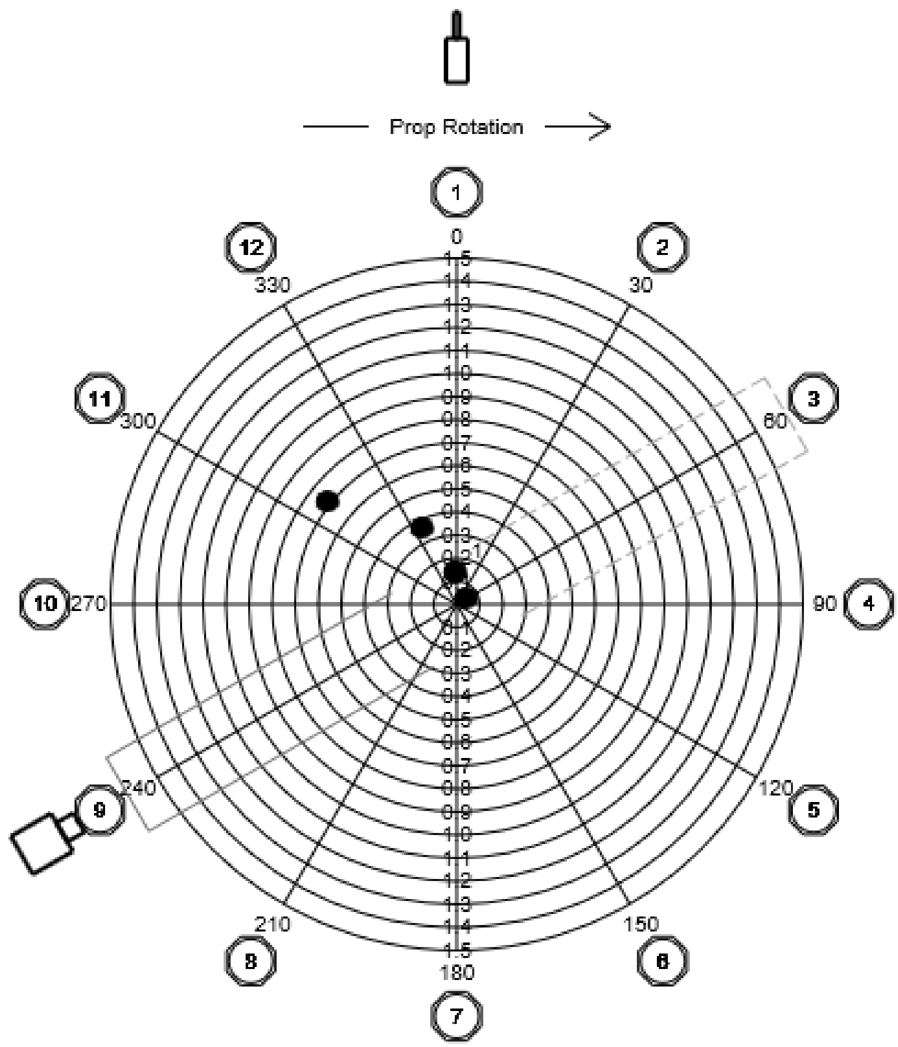

Figure: 3 *Polar Graphical Output From Lycoming Engine*

But more importantly, it will spit out a solution custom-designed for the spinner/propeller installation. For example, if you have 10 mounting screws on the spinner, it will tell you how many grams of weight are needed in which locations. (Figure: 4) Within a couple of runs of the engine we can balance the complete installation with surprising results.

It is often difficult to explain the real advantages of having a properly balanced engine and propeller. But to those that have experienced the transformation, it becomes obvious. The most observable characteristic after having a propeller and engine dynamically balanced is simply a physiological reaction and a general sense that all is right with the power plant. However, aside from this visceral and immediate observation, let's look at some of the longer-term consequences associated with these vibrations. We know that vibration will cause fatigue of many types of materials, but in particular, metal fatigue is of constant concern. The primary purpose of "Lord" mounts on an engine is to isolate the engine vibrations from the airframe. It is interesting that many aircraft owners don't recognize the significance that old, hard, and ineffective motor mounts have on airframe related fatigue. Waiting until the spinner no longer lines up with the cowling as justification to replace the motor mounts is kind of missing the point. But even with new motor mounts isolating the engine from the rest of the airframe we are faced with all kinds of high-cost maintenance directly associated with engine vibration. You have probably seen some of these on your own aircraft. Baffling cracks, exhaust system cracking,

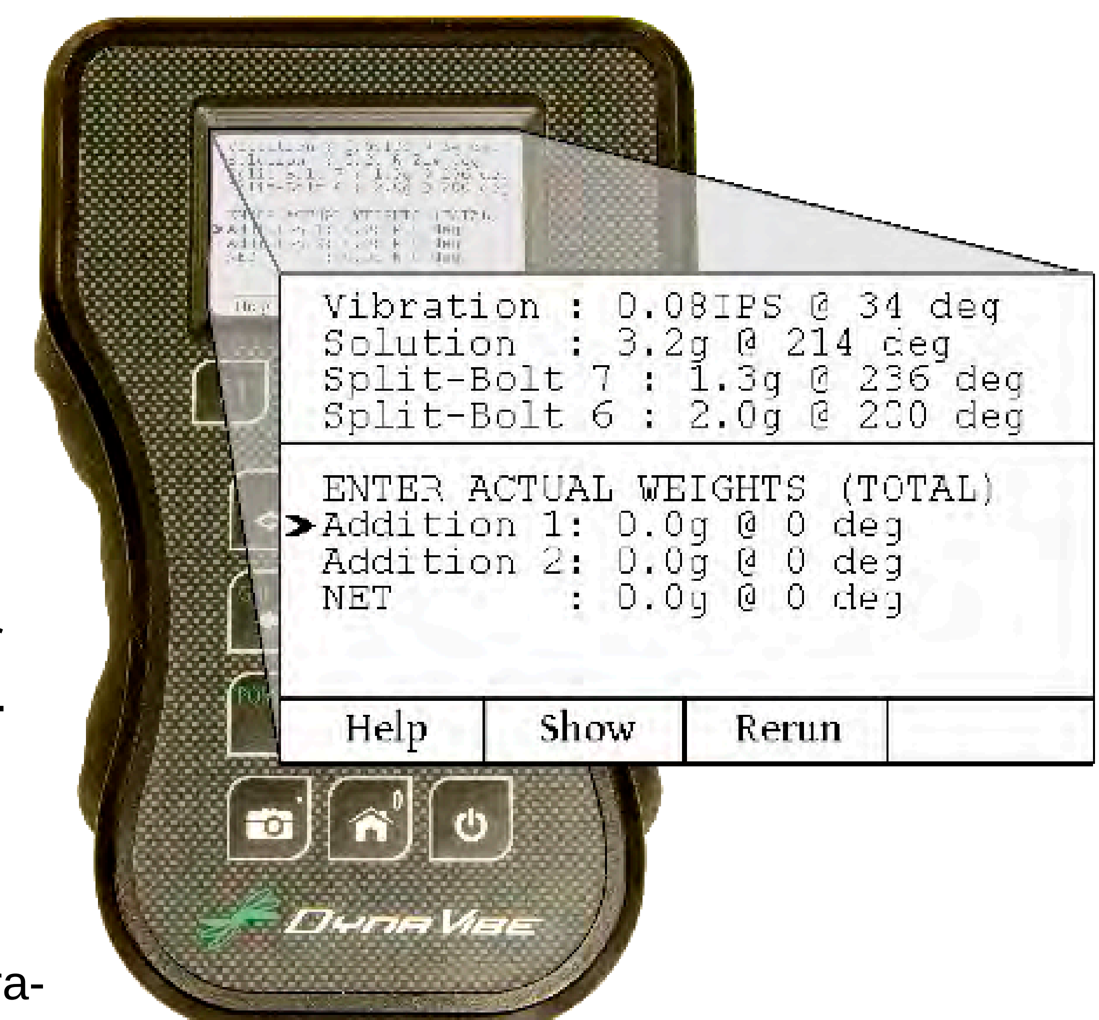

Figure: 4 *Solution Output*

control linkage wear and deterioration, spinner and spinner bulkhead cracking, chafed hoses and wiring, and a whole host of other nit-picky items that continue to chip away at the maintenance budget. Aside from these external items that can be readily observed over a period of time, you have to recognize that there is a whole host of other effects that are occurring internally that are not so easy to spot. There is a whole host of research done to show the increased wear on roller bearings and plain bearings subject to high vibration environments. (Figure: 5) shows an example of an oil injection linkage subjected to propeller imbalance for a period of only 94 hours' time in service. During the first 100 hr. inspection, it was found that vibration between the oil injection arm and the cable assembly had nearly worn completely through all the components including the set screw. If we see this kind of deterioration externally, we know that there will be wear on components that we can't see. We constantly see this example on Rotax engines that are running poorly due to carburetor problems requiring the carburetors to be overhauled: Needle jets and jet needles, worn from hours of operation under higher than normal vibration levels. Needle and seat in the float chamber worn and deteriorated from vibration. Carburetor slides worn from vibration. Throttle and choke cable wear, causing mis-synchronization of the carbs, and causing additional vibration. Ironically, these scenarios can be inadvertently propagated by something as simple as an improper carb synchronization to start with. This in turn leads to vibration which leads to all the aforementioned deteriorations, which in turn, leads to additional vibration. It is a vicious cycle.

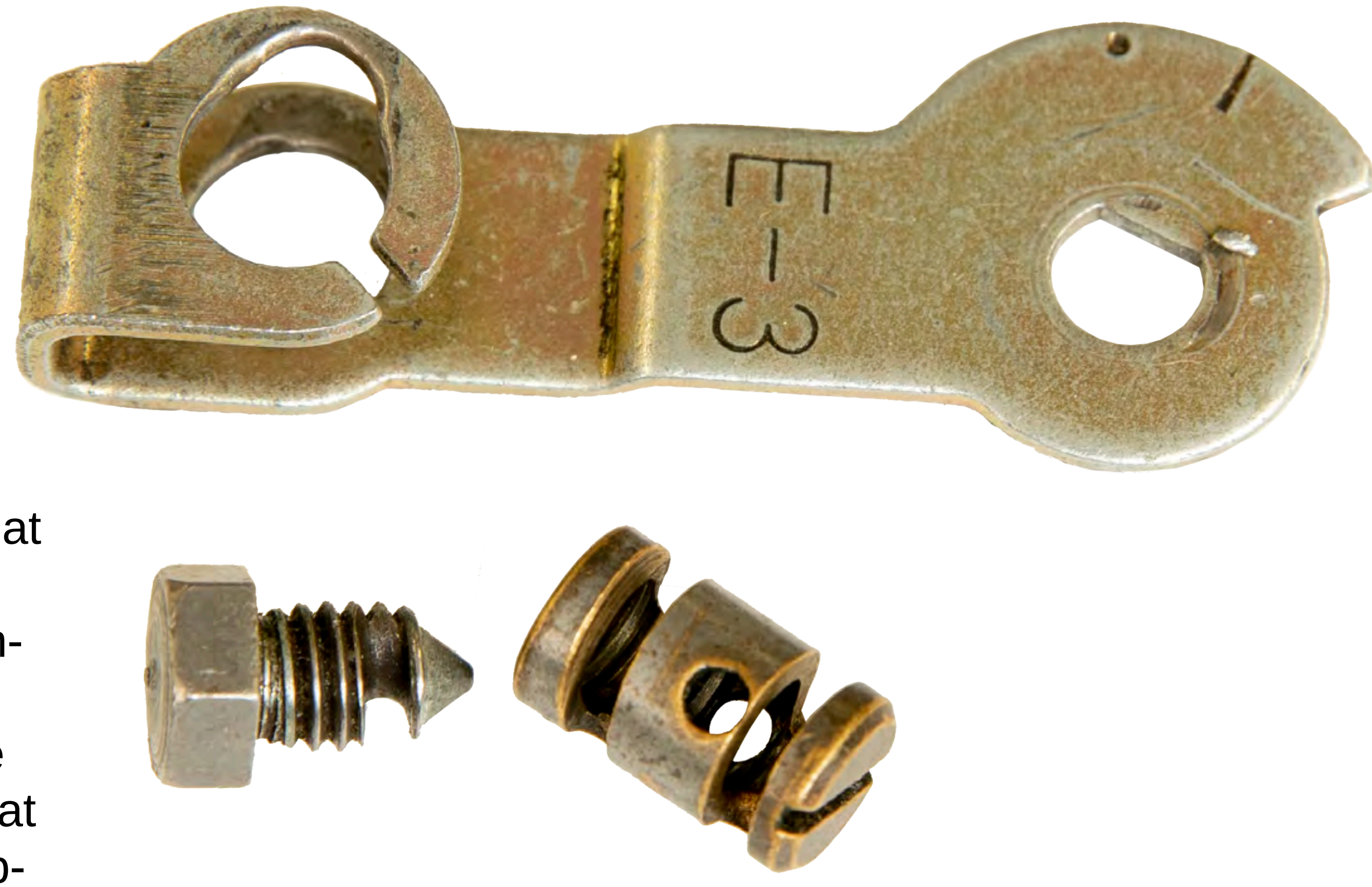

Figure: 5 Wear on Oil Injection Arm

"Vibration is, in itself, an indication that there is something wrong with the aircraft."

Most of the first-generation dynamic prop balancing equipment available all had the ability to generate what we call a "one per" (one per revolution) analysis. This was a big step up in capability over static propeller balancing for the direct drive engines, but the current generation of full-spectrum analyzers like the GX3 changed everything. This was crucial when we started trying to analyze and troubleshoot non-direct

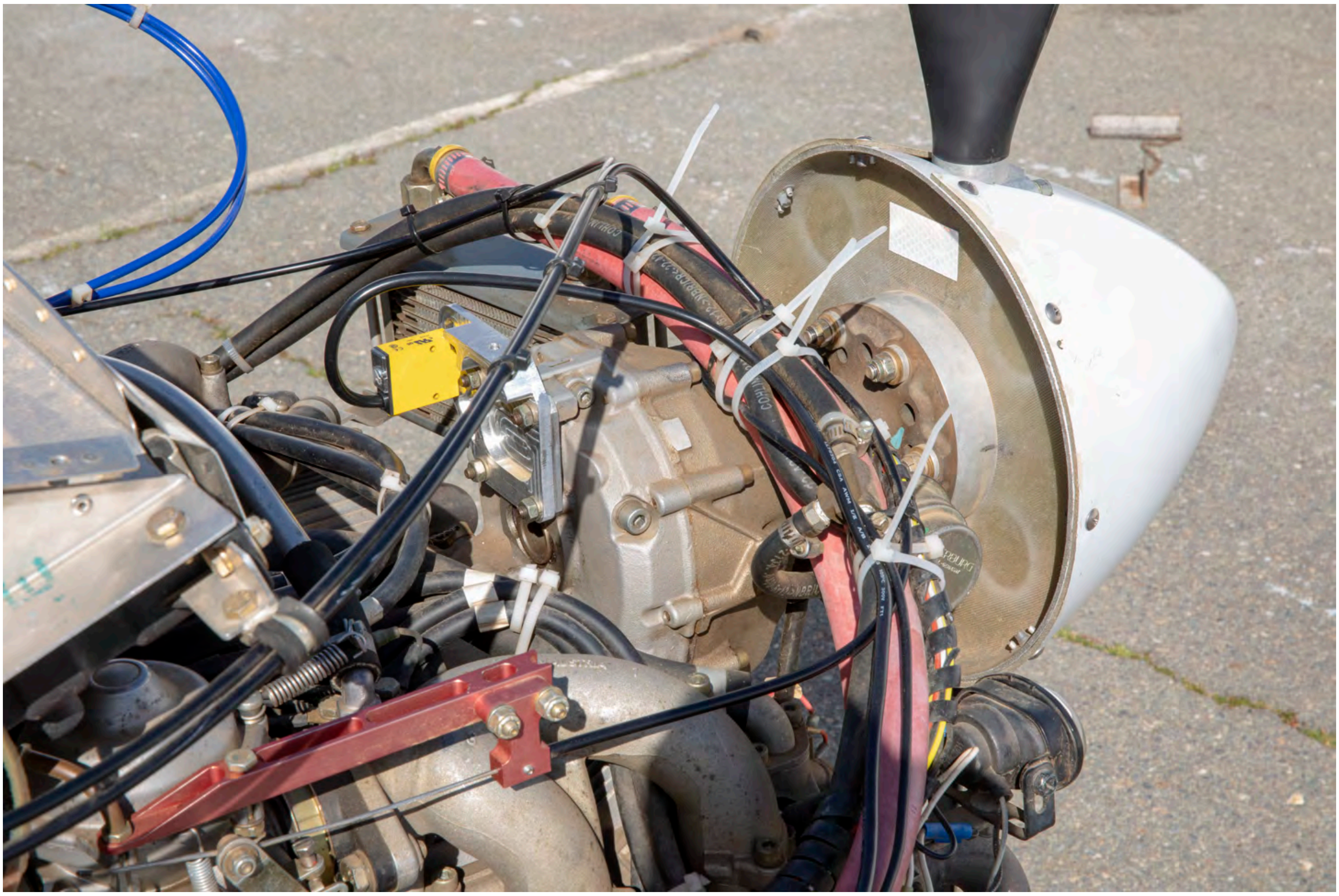

Figure: 6 Sensors Installed On Roatx 912

drive engines like the Rotax engines. Because the engine and propeller are geared, (2.43 for the 100 hp engine), (2.27 for the 80 hp engine), and a whole myriad of gear ratios on the two-stroke engines, there is a vibration signature for the engine that is separate from the vibration signature for the propeller, spinner, and output side of the gearbox. These full-spectrum analyzers now provide us a tool for troubleshooting and setting up an engine, that in our shop, has become invaluable. And although analyzing the Rotax engines could be separate articles for both the 9 series and the 2-stroke engines in themselves, let's look about some of the things that we can see using the full spectrum analyzer. We pulled the Rans Coyote out and set up the GX3 on it for this article. This airplane has an 80 hp Rotax with a 2.27 gearbox and a 2 Blade Warp Drive propeller. (Figure: 6) Because the engine is a "boxer" engine, there is a primary spike that occurs at the 2.27 gear ratio. This is a power stroke on opposing cylinders, 1-2 and 3-4. There is a power pulse that occurs every 360° of rotation and a completion of the four cycle process every 720° of engine rotation. We can correlate anything that affects the combustion process with this 2.27 spike. (Figure: 7) We will often use the GX3 in combination with the digital carburetor synchronizer tool during the carb synchronization process to isolate synchronization issues from other discrepancies. Because the crankshaft and the prop shaft are not "directly" connected on a Rotax engine, at low RPM the position of the crankshaft to the propeller may vary as much as 30°. This can be tricky to suss out the root cause or "causes"

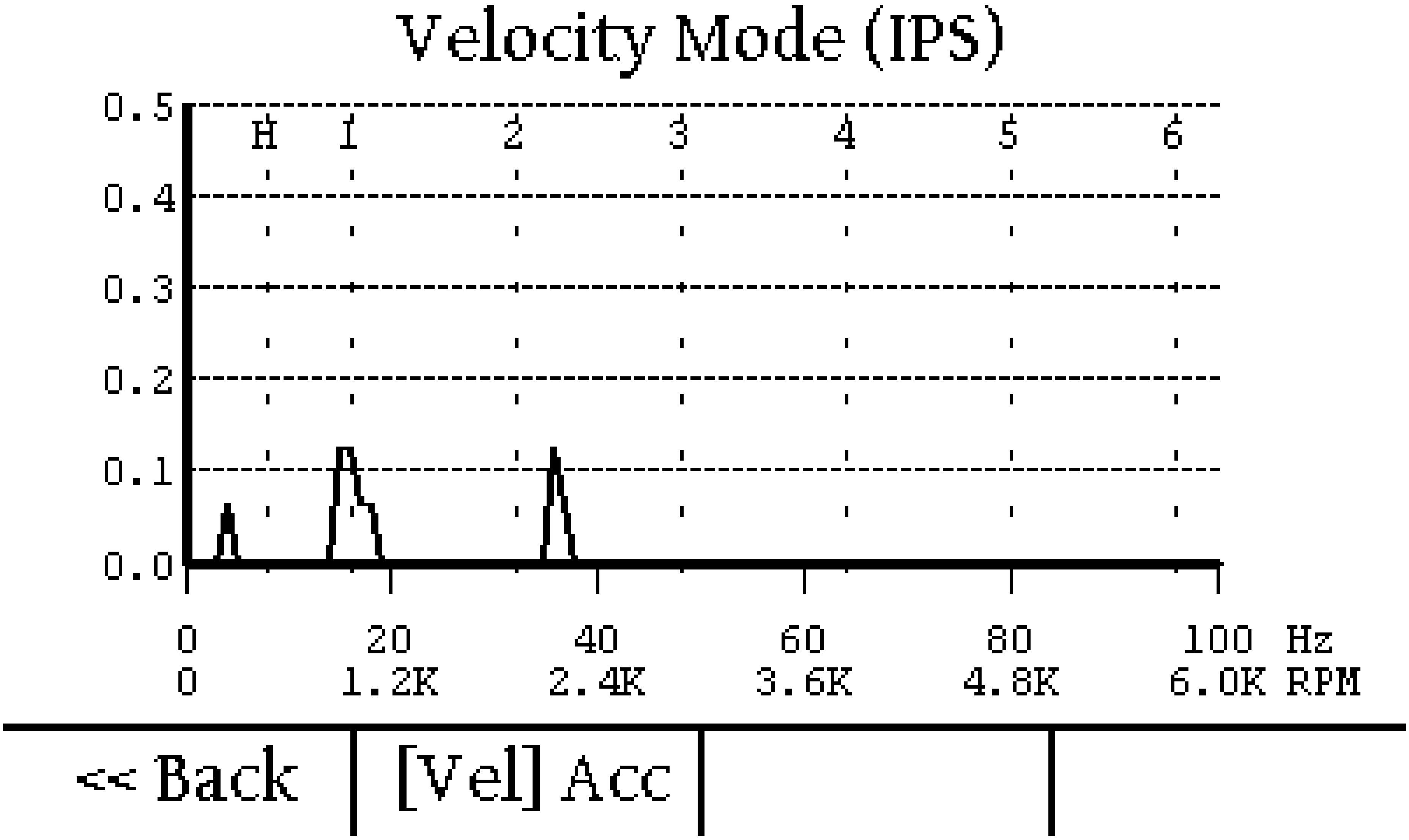

Figure: 7 Full Spectrum Output.

of the problem without the vibration analysis. A prop that is out of balance can cause the engine to vibrate, which can in turn cause the carburetors to shake, which in turn can cause the fuel inlet needle to unseat within the carburetors, allowing excess fuel, and causing a rich mixture, which can cause the engine to shake worse. The same symptoms can occur with a perfectly balanced propeller, but induced by excessive friction torque on the gearbox. In both cases the excessively rich mixture is the cause of the shaking. However, this rich mixture is a symptom not the cause. Being able to identify the root cause of the problem is the goal. Having the proper tools makes the process of troubleshooting much easier. There are many other problems that can be identified with a full spectrum analyzer. For example, on a direct drive engine we are seeing a power pulse every 180° of rotation. It's easy to spot a dead cylinder as a 1/2 per spike. Odd combinations of vibration frequencies may be associated with an out of balance alternator or some other accessory running a drive belt and a different speed ratio. We will often see frequencies that seem to correspond with a propeller, but are not caused by an out of balance scenario, rather as a result of a ground adjustable propeller blade being pitched slightly different than the other blades. To this day we are still collecting data on a myriad of different scenarios.

Vibration is, in itself, an indication that there is something wrong with the aircraft. It is surprising some of the things that we find during the process of "balancing the propeller". There is a lot of satisfaction in taking an airplane into the shop, hooking up all the test equipment, Identifying and fixing the root cause problems, and seeing how smooth we can make the airplane. Remember, it's not just about the propeller.

Bing 64 (CV) Carburetor Part 1

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This article will focus on the Bing 64 CV (Constant Velocity) carburetor. The basic principal of operation utilizes a vacuum operated slide that varies the venturi size which, in turn, maintains a constant velocity of air passing through the carburetor at all engine power settings. The advantage of the CV carburetor is that it supplies the engine only as much fuel/air mixture as the engine demands. For an aircraft applications, where we have large excursions in altitude, this is exactly what the doctor ordered. The Bing 64 carburetor (Figure: 1) has become, hands-down, the most popular carburetor used in the light sport industry. It is used on both the Rotax 912 as well as the 914. It is also used on the HKS 700 E, the Stratus, the Rotec Radial, and the Jabiru engines. This carburetor has a long history of great reliability, on a plethora of aircraft. The carburetors are easy to maintain with very few moving parts, rely on good design, and relatively simple operation to garner their great reputation. Most of the problems that we see on the CV carburetors are created by the operators, inadvertently and primarily from a simple lack of knowledge on basic operation, maintenance, and troubleshooting. In our Light Sport maintenance classes, there's one universal area that will cause a student to sit up straight and pay attention: Troubleshooting! We tell the story constantly about how easy it is to troubleshoot an engine problem. (For this article we will say engine/carburetor problem). It's as simple as this. Step 1: Inspect the engine/carburetor to find out what has changed from the stock configuration. Step 2: Change it back to stock configuration. Step

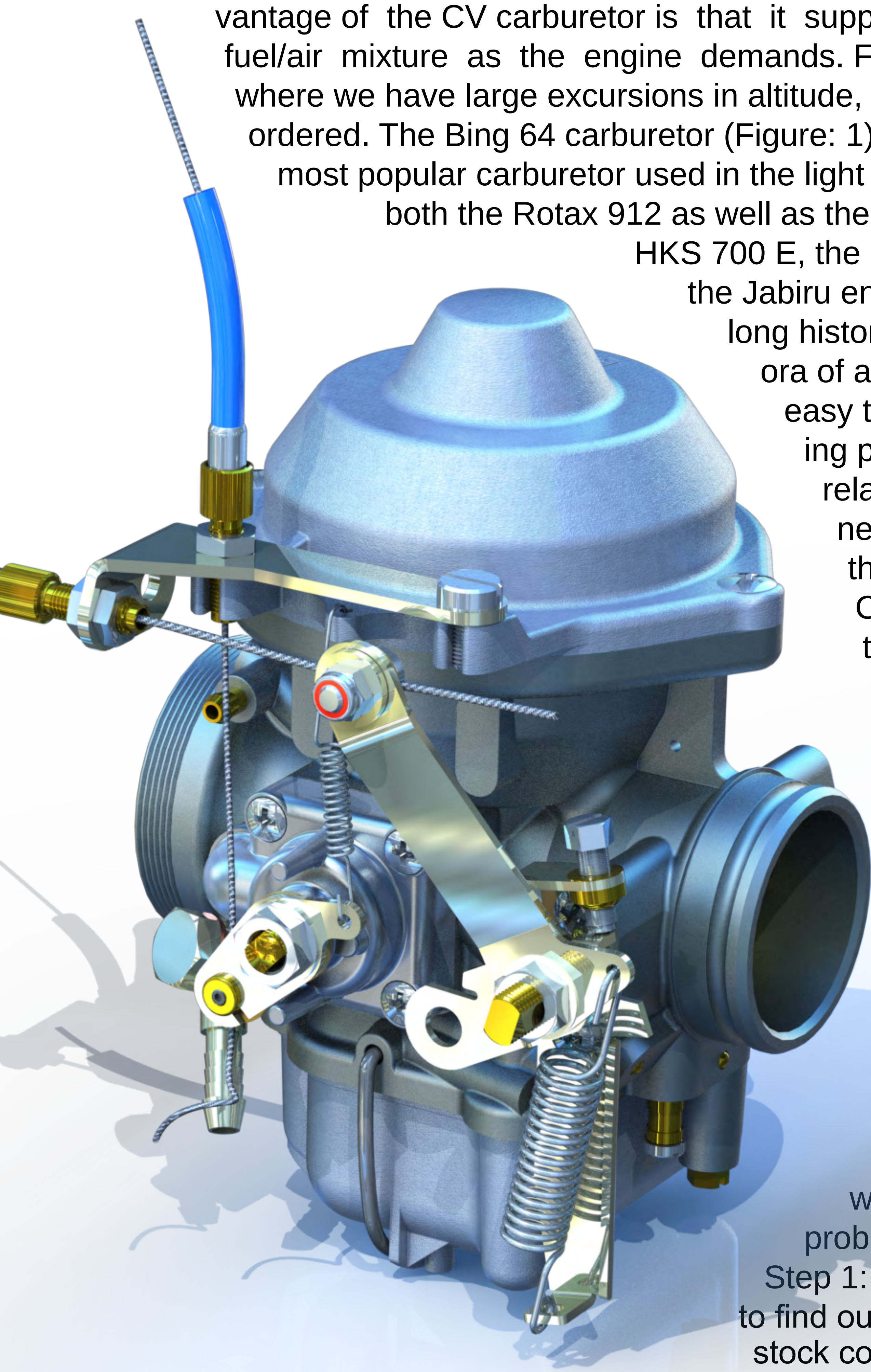

Figure: 1 Bing Type 64 (CV) Carburetor

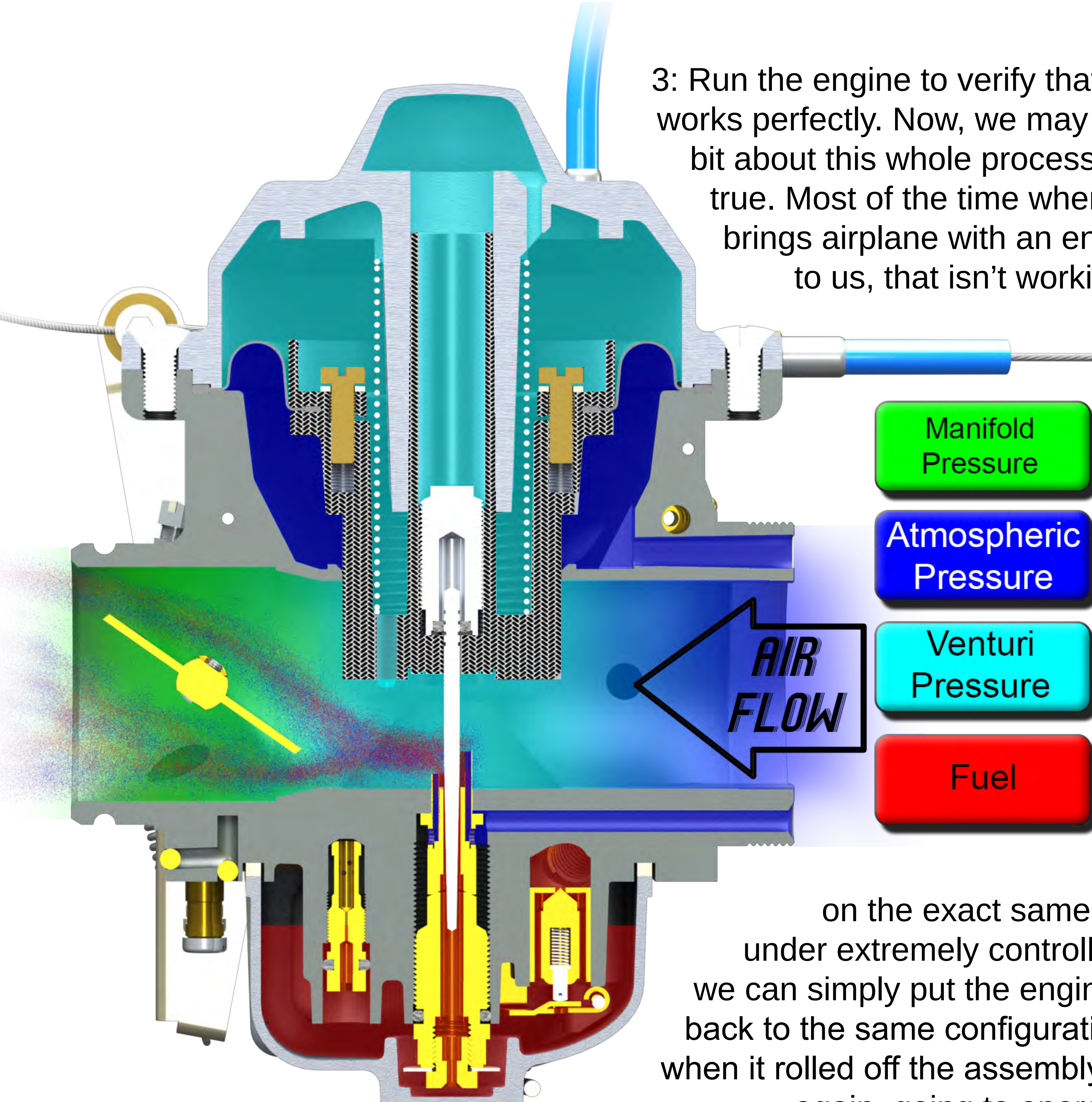

Figure: 2 *Pressures Within The CV Carb*

3: Run the engine to verify that everything works perfectly. Now, we may be joking a little bit about this whole process, but it really is true. Most of the time when a customer brings airplane with an engine/carburetor to us, that isn't working properly. We simply hunt to find out what has or hasn't been done to the aircraft that now makes it different than when it was a new engine. Keep in mind that these engines are all manufactured on the exact same assembly line, under extremely controlled conditions. If we can simply put the engine/carburetor back to the same configuration which it was when it rolled off the assembly line, it is, once again, going to operate like a "new engine". Of course, the problem with this whole concept is having the requisite knowledge to be able to easily identify what is no longer in the "stock configuration." In order to make good troubleshooting decisions, we need to start with a good understanding of the CV carburetor's theory. There are 3 primary elements necessary for making an engine run, fuel, air, and spark. Two thirds of this equation is the responsibility of the carburetor. The job of the carburetor is to supply, not only the total quantity of fuel and air (power), but also to supply the correct ratio of air/fuel (mixture) for each power setting selected by the pilot. The pilot can select a power setting on the CV carb by moving the throttle lever which is hooked directly to the throttle assembly. However, unlike a conventional carburetor, this does not automatically allow air and fuel into the engine. You can think of it like the captain of a ship sending a signal to the engine room. He moves the levers on the bridge which in turn sends a signal to the engine room telling them to add more power. By opening the throttle valve we reposition the throttle valve, however, the piston (not controlled by the pilot) is in control of how much air flows through the carburetor. The CV carb works on the principal of varying the pressure differential above and below the piston, which, in turn, varies the venturi opening like a conventional slide carburetor. During the engine intake stroke, a vacuum is presented to the carburetor via the intake manifold. This low-pressure draws air through the carburetor. (Figure: 2) The motion of the air, under the slide (piston), acting as a venturi creates a pressure drop. This pressure drop is transmitted through passages in the piston to the enclosed chamber above the piston. The upper and lower half of the piston is separated by a rubber diaphragm that allows the movement of the piston. The pressure below the piston and diaphragm is vented to atmospheric pressure via a passage from the inlet face of the carburetor. The greater the pressure differential, the higher the piston rises, the larger the venturi opening. Fortunately, unlike the ship metaphor, the signal transmitting from the throttle valve to the piston is smooth and nearly instantaneous. It is, however, one of the reasons that the Bing carburetor can get away without the utilization of an accelerator pump. If the pilot were to "jump" on the throttle suddenly, the inertia of the piston limits how quickly it can respond. Additionally, when the venturi is suddenly exposed to the throttle being opened, the velocity of air in the venturi increases significantly, creating a lower pressure. This sudden pressure drop is not only the pressure that is transmitted to the top of the diaphragm that causes the slide to move up, but it also creates an increase in vacuum. This vacuum at the diffuser draws additional fuel from the needle jet providing for a richer than normal mixture that is needed for the acceleration process.   In transitioning to talking about fuel, we need to be aware that the fuel distribution is also out of the hands of the pilot. Unlike a conventional aircraft, the Bing carburetor has no mixture control for the pilot to manipulate. The fuel distribution from idle to full throttle is also automatically controlled within the carburetor. Except for the Idle and choke circuit, the fuel is injected into the carburetor body at the diffuser. This component is also known as an atomizer. The purpose of the diffuser is to inject atmospheric air from the lower inlet of the carburetor at the exact location that fuel is exiting the needle jet. This breaks up the fuel into very small (atomized) particles, which enhances the distribution of fuel within the intake manifold, as well as improves the combustion process. The distribution of fuel is regulated by several systems. The idle jet, the needle jet and jet needle working together, and the main jet have control over the mixture at various segments of throttle

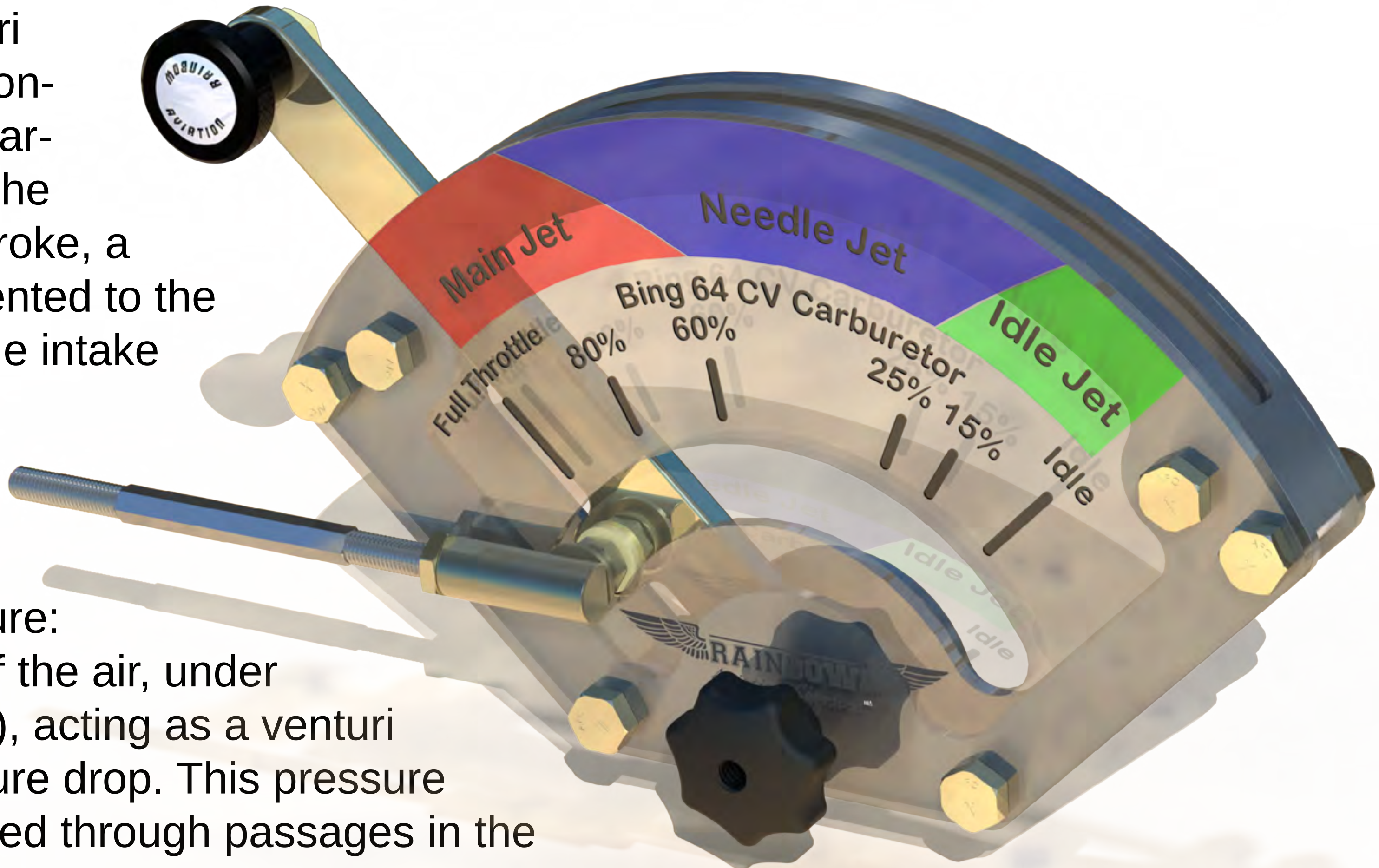

Figure: 3 *Jet Effectiveness vs Throttle Settings* setting. There is overlap within the systems from idle to mid range and from mid range to full throttle. (Figure: 4) Once we are above the 25% throttle setting, all of the fuel is routed in series through an assembly of fuel distribution components. Starting at the bottom of the float bowl, the fuel travels upward through each of the components starting with the main jet. The main jet is screwed into the mixing tube. The mixing tube is screwed into the lower portion of the carburetor body holding the needle jet into the diffuser which, in turn, is pressed into the carburetor body. Simultaneously, the jet needle is being automatically positioned by the piston within the needle jet. As the piston rises, so dose the jet needle. This provides for an ever increasing amount of fuel that corresponds with the amount of air that is being allowed into the engine. When the piston and needle rise high enough, the orifice size from the needle jet / jet needle becomes larger than the orifice size of the main jet. Because these components are in series, the smaller of the orifices become the controlling factor. The resistance to fluid flow in each of the jets contributes to the overlap from mid range to full throttle. A typical slide carburetor, where the pilot controls the piston via a direct cable connection to open and close the throttle, is at a great disadvantage. As the aircraft gains altitude, the air density diminishes whereas the fuel density remains the same. This inevitably results in a rich mixture. The CV Carburetor on the other hand, senses the reduced atmospheric pressure on the lower half of the diaphragm, and the piston lowers in the body of the carburetor. This happens automatically even though the throttle valve position is still in the full open position. Because the piston is lowering the needle jet / jet needle restriction also automatically reduce the fuel to lean the mixture. You can start to get a sense for the brilliance of the design. In part 2 of this article, we will dig even deeper into the inner workings of the CV carburetor. Once you have a complete understanding of the carburetor, you can't help but have a great deal of confidence in your engine. After all, the carburetor is controlling two of the three things needed for your engine to run, fuel and air.

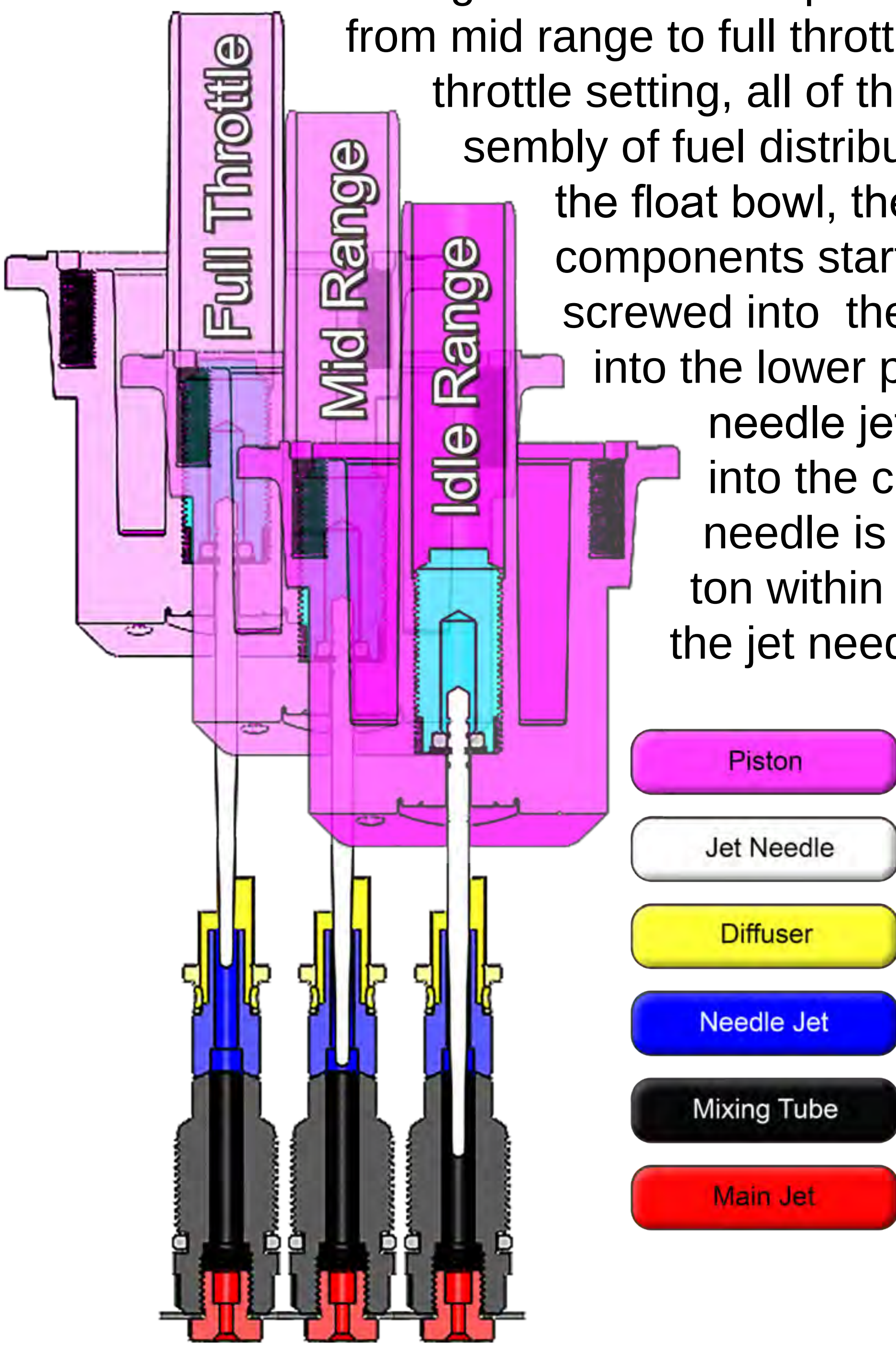

Figure: 4 Full Throttle and Mid Range

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Bing 64 (CV) Carburetor Part 2 (Starting Carb)

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In Part 1, we examined the basic principals of operation of the CV (Constant Velocity) carburetor. In this article we will take an in depth look into one of the most misunderstood subsystems of the carburetor, the “Starting Carb”. It is often referred to as the “choke”, however, this doesn’t properly describe the operation of the Starting Carb. A choke is, really, a valve on the inlet side of a carburetor used to restrict the flow of air through the carburetor. This results in a low pressure with the intake manifold and carburetor system as a whole. This is different from the carburetor butterfly valve which is located down stream from the fuel nozzle which also restricts the airflow creating a low pressure, but only within the intake manifold. The choke valve which is located before the fuel nozzle presents a low pressure to the entire carb. This low pressure, naturally draws more fuel through the carb and into the intake manifold resulting in an enriched mixture. The starting carburetor, on the other hand, is in fact a separate carburetor within the larger carburetor. This starting carb provides for an enriched mixture by introducing addition fuel as well as air during the starting sequence. The starting carb on the CV carb is different from that incorporated into the slide type carburetors used on the Rotax 2 stroke engines. The (Bing 54) carburetors, used on the 2 stroke engines also use a

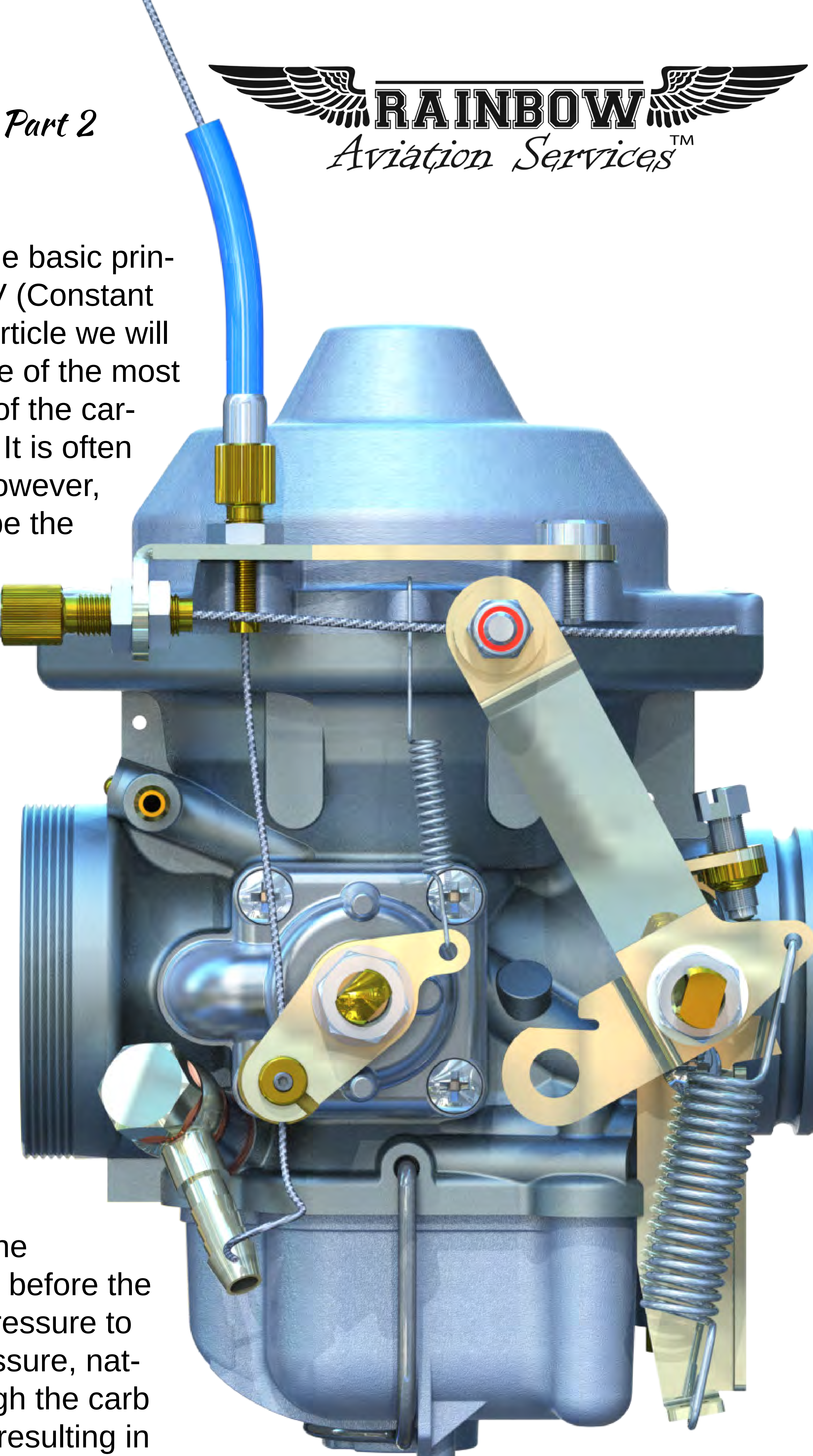

Figure: 1 Starting Carburetor in the Closed /Off position starting carb, but it operates in an On/Off capacity. On the CV carb the starting carb operation is adjustable allowing for full application during start and cold weather operations, and the ability to reposition the "choke" for less affect as the engine warms.

The starting carburetor mechanical components are located on the side of the carburetor. (Figure: 1) The starting carb is actuated via a Bowden cable similar to the cable used to operate the throttle. The starting carb is held normally in the off (closed) position by a spring. One of the more common carburetor problems, that we see, is a rough running engine at Idle up through the mid range of operation. If the "choke" cable is sticking in the on or partially on position, the results will be a very rich mixture and rough running engine. We have seen several instances of owners sending their carbs in for overhaul because they were running poorly at lower RPM settings, only to have their freshly overhauled carbs respond just as poorly as before they were overhauled. Frustrated, they brought their aircraft to our shop only to have us identify that the friction within the choke cable was not allowing the very small return spring to pull the choke to the off position. If your engine is running poorly at the low end of the operating range, be sure to look to insure that the actuation arm is hitting the lower stop on the choke housing. Many aircraft manufactures replace the stock choke return spring with a slightly stronger spring.

"If we crack the throttle during the starting process, we have essentially negated the effects of the starting carburetor. The throttle must be closed in order for the choke to function."

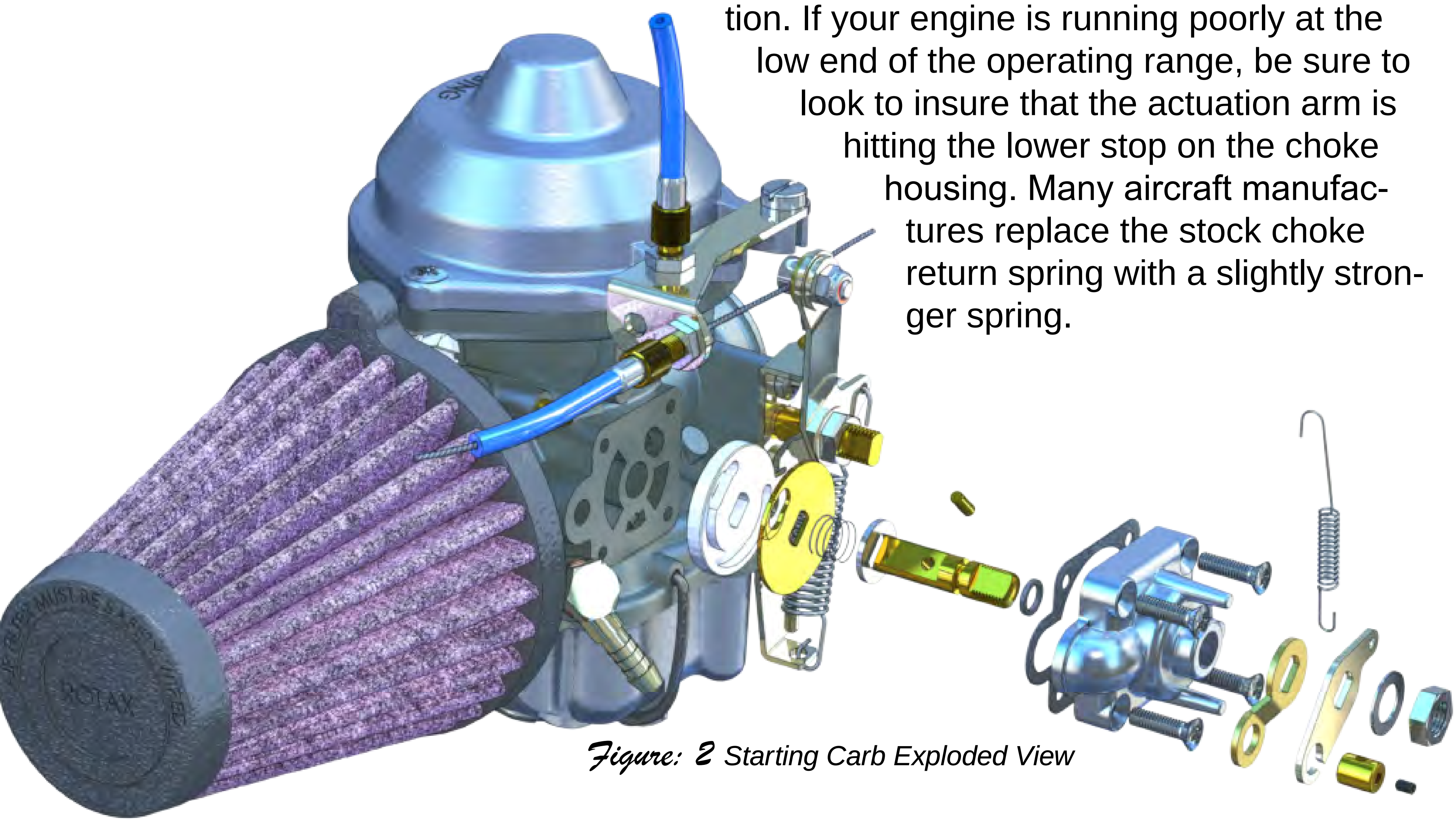

Figure: 2 *Starting Carb Exploded View*

Let's take a little closer look into the theory behind the function of the starting carburetor. In order to utilize the function of the starting carburetor we utilize the same principles as a choke system. However, recall that we indicated that the starting carburetor is a separate carburetor in itself. As a result, we can use the throttle butterfly as a choke valve to create a low-pressure on the intake manifold side of the carburetor. When the throttle is fully closed, and only when it is fully closed, the pressure on the intake manifold side of the carburetor is much lower. We use this low-pressure to draw fuel from the very bottom of the float bowl up through a small “starting jet”, then up through a “pickup tube” into passageways within the body of the carburetor and eventually up to the face of the starting carburetor valve. (Figure: 3) The starting carb “valve” either blocks the fuel from transitioning through the internal passageway to the outlet to the engine or is positioned to allow fuel to pass. In the partially choked position a small orifice is opened up at the bottom of the starting carb. In the full choke position, a much larger orifice is now opened up. (Figure: 4) Keep in mind that the basis for being able to draw fuel all the way from the bottom of the float bowl, up through the starting carb, and through the passageways into the intake manifold is based on having a significant pressure differential between the pressure in the intake manifold and the pressure within the float bowl chamber. If we crack the throttle during the starting process, we have essentially negated the effects of the starting carburetor. The throttle must be closed in order for the choke to function. Trying to employ typical Continental/Lycoming starting procedures generally results in much frustration. The necessity for cracking the throttle has been addressed in the design. The large hole located directly to the left of the starting carb valve is a passageway from the inlet side of the throttle carburetor body into the choke housing assembly. This allows air to enter into the choke housing and be directed around the starting carb valve assembly. At this point the air transitions into the cut-out slot in the brass plate that makes up one half of the starting carburetor valve assembly. At this point the air combines with the fuel and transitions into the passageway within the carburetor body and exits the outlet on the downstream side of the throttle valve and into the intake manifold. (Figure: 5) As you can see, the

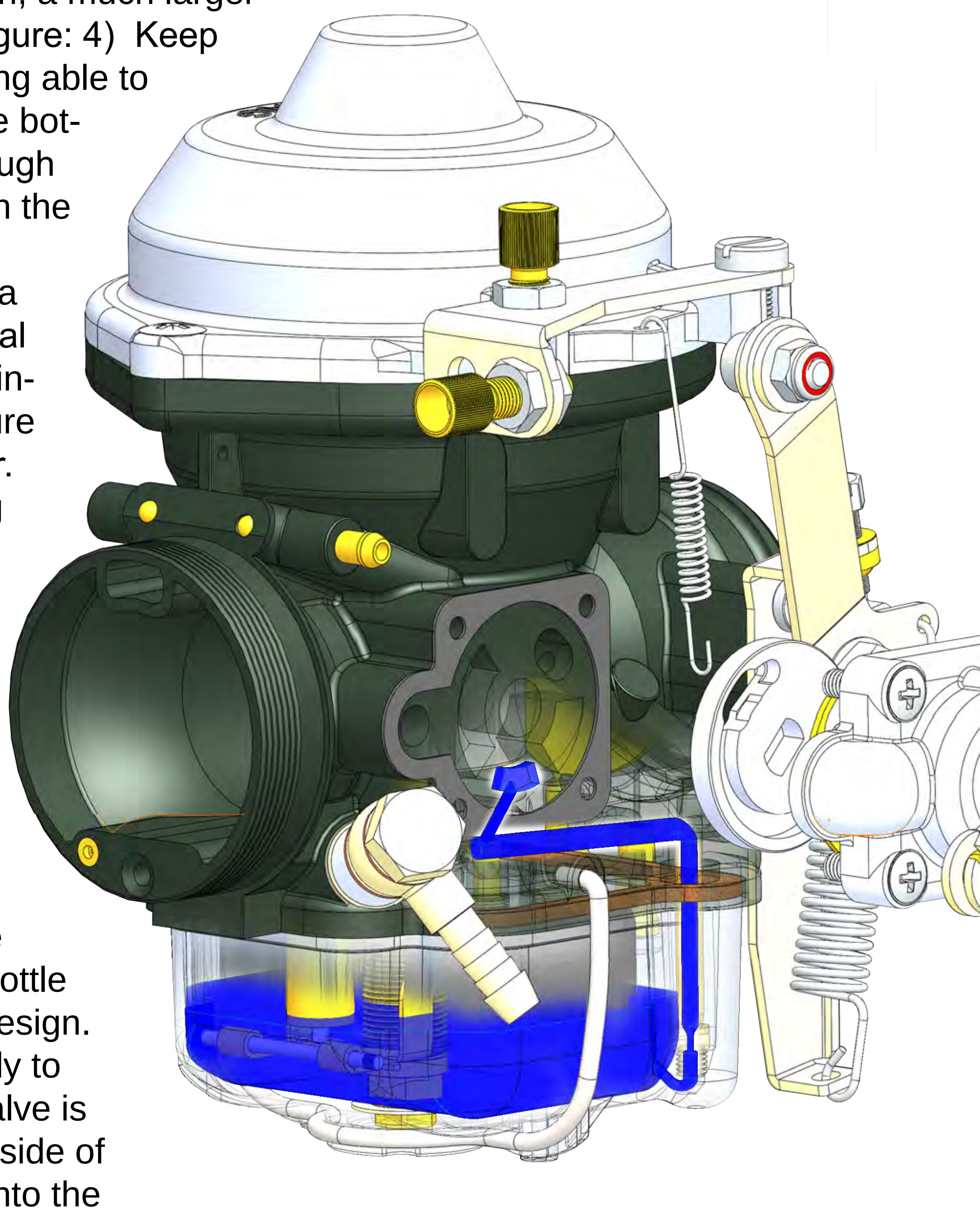

Figure: 3 Fuel Supply to the Starting Carburetor

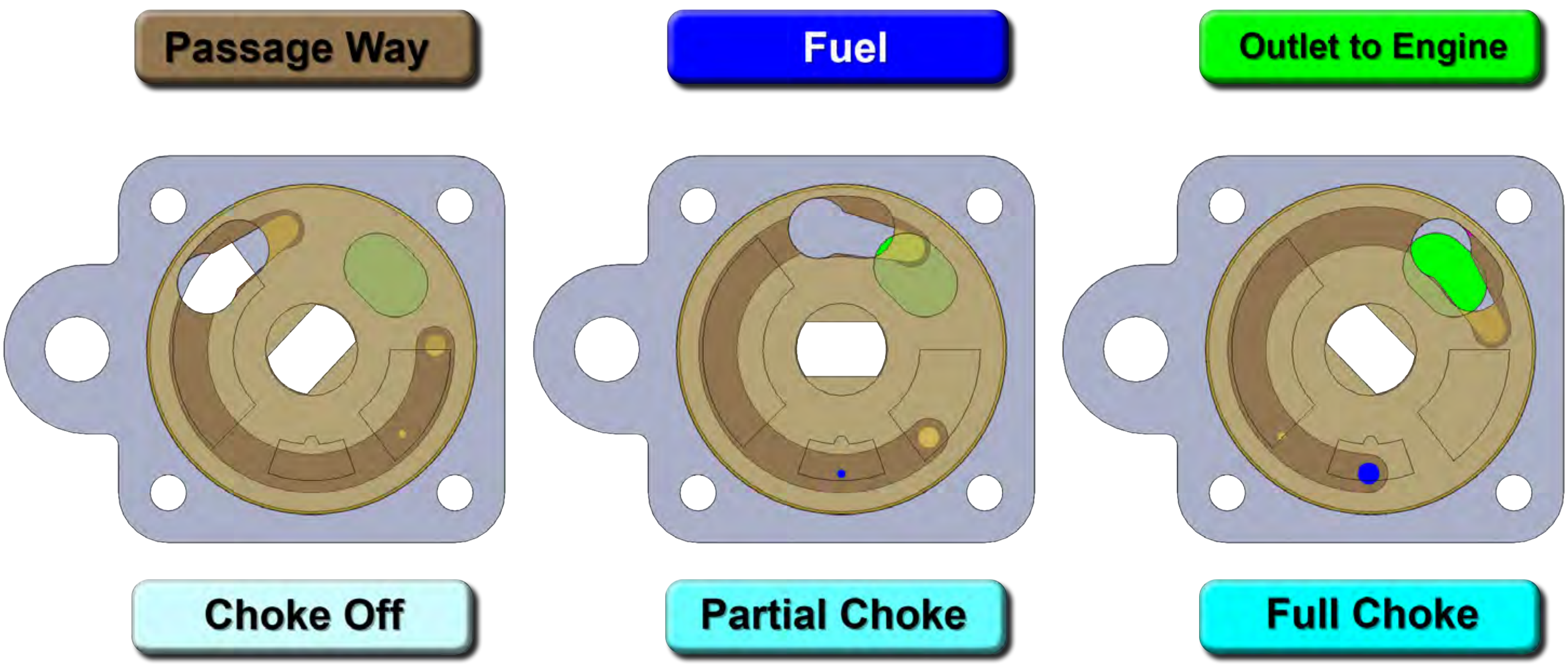

Figure: 4 *Starting Carb "Valve" Positioning*

starting carburetor system is really quite simple and brilliant. Properly maintained, starting your engine should never be difficult at all. Now that we understand the system, let's take a look at some of the problematic areas which we see on a regular basis. Located within the float bowl, but way down inside where the pickup tube is located, is a starting jet. Most people aren't even aware that it is there. It is not uncommon that contamination will plug this jet because it is located at the very bottom of the float bowl. The size of the starting jet is very small and old fuel can often times form a film over the orifice. This can be very easily inspected by simply removing the starting jet with a small straight slot screwdriver. The pickup tube that is located within the body of the carburetor, which transitions down to the starting jet, can also become contaminated and plugged. Make sure, at a minimum, that you blow through this tube to ensure there is no restriction. Speaking of restrictions, the orifice located within the starting carburetor valve assembly, that is used for the partial choke position, is also very small and sometimes becomes blocked. If the engine starts in the full choke position, but quits as you moved to the partial choke position, you may want to pull the choke assembly apart to inspect for contamination on the small orifices. Anytime we see someone installing a primer onto the Rotax engine to help with the starting process, we almost always find that this fuel passageway is plugged up. There is no need to ever install a primer on the Rotax engine.

The last, but most common problem that we see, is with improperly trained pilots not recognizing the necessity for having the throttle in the closed position during the start sequence. Without that pressure differential we simply can't get the fuel all the way up from the bottom of the float bowl. On the other end of the spectrum, rather than not being able to get fuel into the engine during the start, if you find your engine running rough, especially at low RPM, you might want to pull the choke assembly apart and look for contamination between the valve assembly and the face of the carburetor body where the two meet. Even a small chunk of contamination will off-seat the valve allowing fuel to leak under the disc and directly over into the passageway to the carburetor outlet. With this scenario it doesn't matter where the choke is positioned, it simply will leak fuel across the face of the valve. There is a small spring located on the starting carburetor shaft that maintains light pressure against the starting carburetor valve assembly and the body of the carburetor. Ensure that all of these components can float on the starting carburetor shaft. There are both calendar time limits as well as flight hour limits for the carburetor overhaul. This overhaul should include an inspection of the starting carburetor system as well. We find these carburetors to be nearly bulletproof. The caveat is, you can not expect them to be bulletproof unless you do the required inspections, maintenance, and overhauls. And the key to being able to accomplish any of these three tasks is a good theoretical understanding of how the carburetor works.

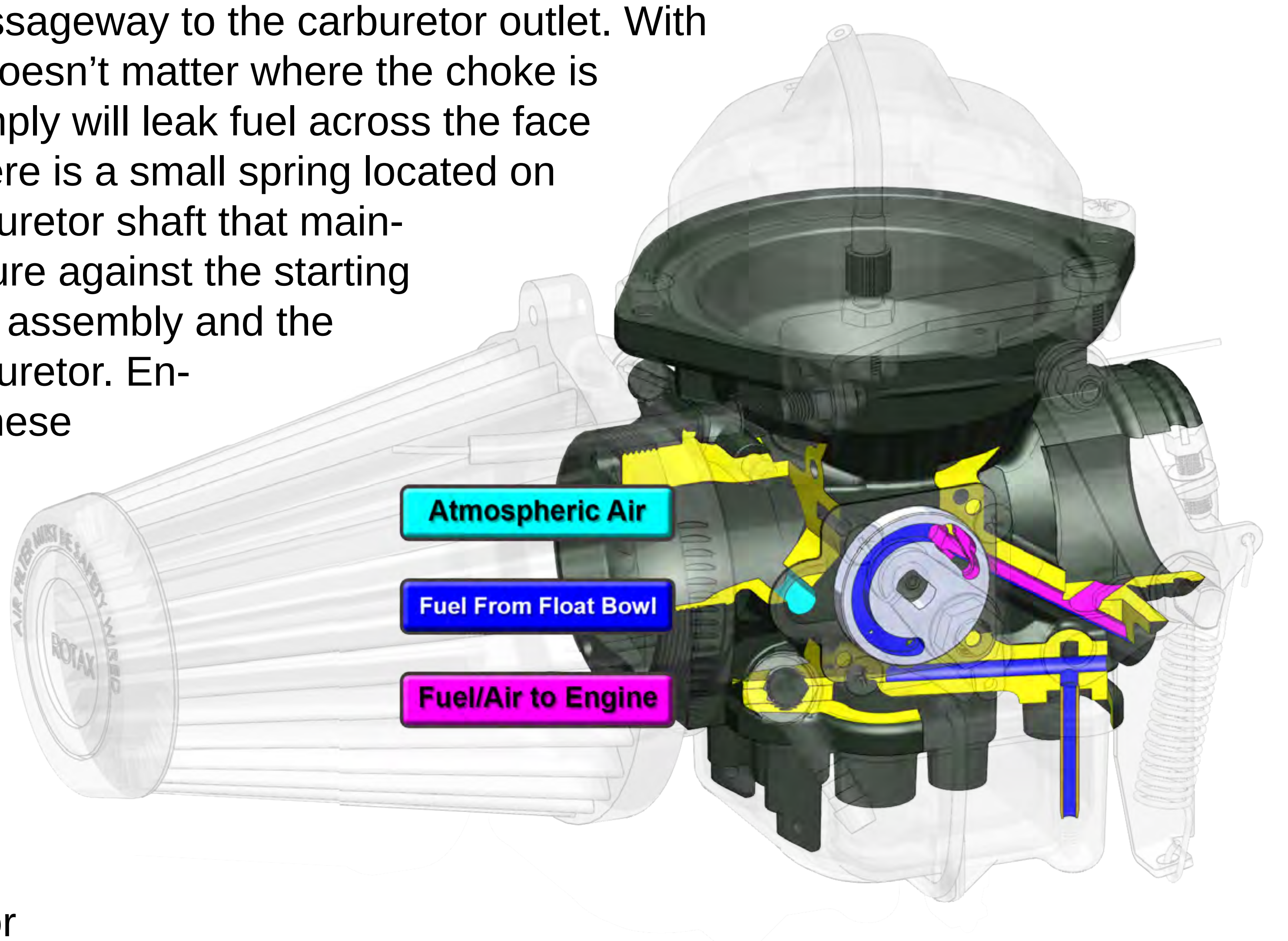

Figure: 5 Cutaway of the Passageways that make up the Starting Carburetor

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In Part 2 of this article, we talked about the starting carburetor (choke) system. We can run the engine at lower RPM settings only on the choke system, but as soon as we reset the choke system to the off position, the engine is now running on the idle circuit only. We often use this as a troubleshooting exercise. If the engine runs with the choke partially on, but dies as the choke is placed in the off position, it is an indication that the idle circuit is the culprit. It is absolutely essential that the idle circuit be set up and functioning properly. We use the idle circuit on every flight, and it is a surprisingly important system within the carburetor. Aside from the practical aspects of having a properly operating idle circuit, there are many correlations with the idle circuit malfunctioning and other engine problems, ranging from increased maintenance to engine stoppage and even engine failure.

If you follow our articles on a regular basis, you already have an insight into our underling premise that all successful troubleshooting, maintenance, and operation, comes as a result of a solid foundation of the theory and physics surrounding the subject matter. With that being said, let's dig into the theory of the Idle circuit.

With the slide (piston) completely closed, the vacuum present at the main fuel outlet is not sufficient to draw the fuel up from the main jet, through the mixing tube, needle jet, and into the diffuser and throat of the carburetor. At low power settings we need to supplement the fuel air system with an auxiliary fuel-air system consisting of an idling air jet, Idle jet, bypass, idle outlet bore, and an idle mixture screw. (Figure: 1)

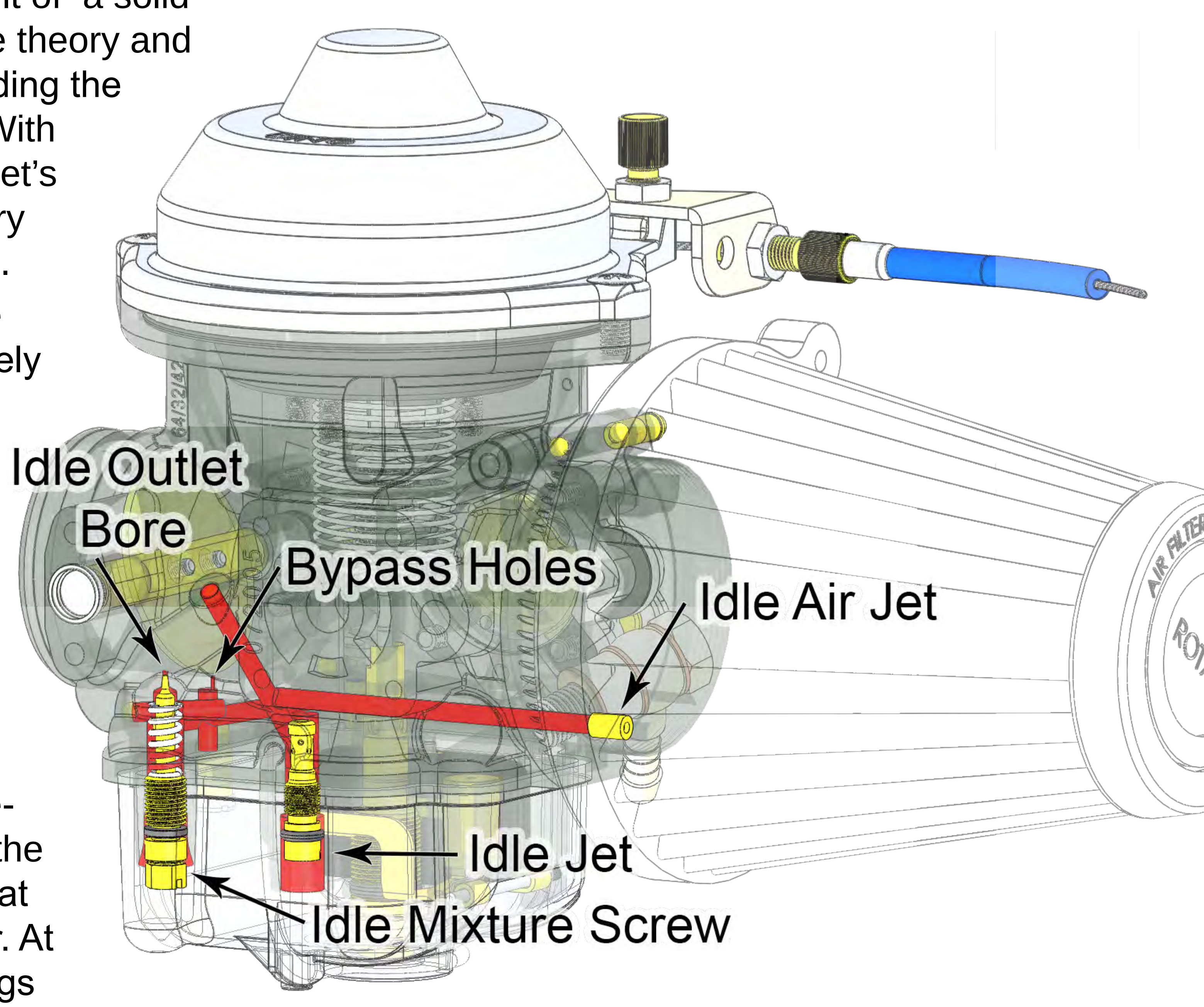

Figure: 1 Idle Circuit Components

The idling air jet is located on the inlet face of the carburetor and restricts the volume of air that can enter the idle mixture circuit. Manufactured from brass, it is pressed into the body of the carburetor and is normally not considered a replaceable component. The orifice size is approximately .020” in diameter. An orifice this small is easily plugged with contamination and one reason why it is located inside of the air cleaner.

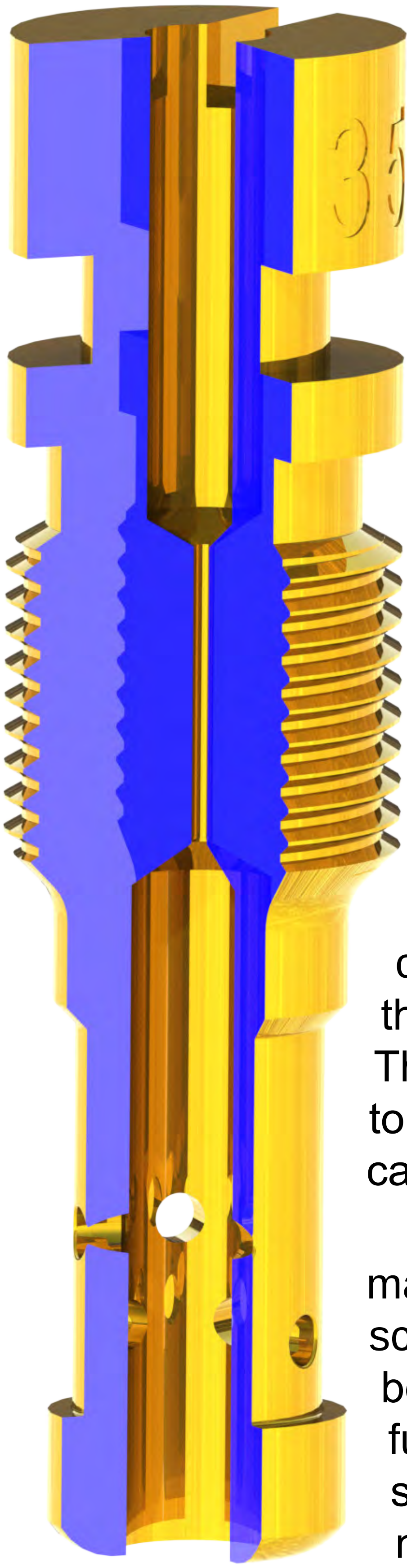

Figure: 2 Idle Jet

The idle jet is made from brass. (Figure: 2) The jet size used on the Rotax 912 idle jet is a number 35 which designates that the orifice size as .35 mm. The jet is inset into the body of the carburetor inverted with the head of the jet facing down into the float bowl. This draws fuel through the jet orifice into the body of the jet. The body of the idle jet consists of eight radially drilled holes in the body. This acts as a fuel atomization chamber which mixes the incoming air from the idle air jet with the fuel from the float bowl. This mixture is excessively rich and will be used to supplement the air that is coming through the carburetor, past the throttle valve.

The idle mixture screw (Figure: 3) is also manufactured from brass. The idle mixture screw works in conjunction with the idle outlet bore to create an adjustable needle valve. The fuel and air transitioning through the idle mixture screw and idle outlet bore have already been mixed. Allowing more of this already excessively rich mixture into the carburetor will result in an enrichened fuel air ratio at idle. If you came up through the ultralight ranks, operating a two stroke engine, you may be familiar with the idiom, which we used to remember which direction to turn the idle mixture screw, “in” richen, lean “out”. This works for the Bing 54 slide carburetors used on the Rotax 2-stroke engines. However, the Bing 64 CV carburetors are exactly the opposite. To enrichen the mixture we need to screw the idle mixture screw “out” or counterclockwise, and “in” or clockwise to lean out the mixture.(Figure: 4)

The bypass is located at the six o’clock position in the throttle body just under the throttle valve. These are two very small (.020”~) holes, nearly invisible, located coincidently

Figure: 3 Idle Mixture Screw

just at the position where the throttle valve makes contact with the body of the carburetor. These holes work in conjunction with the idle outlet bore. The venturi effect created by the position of the throttle valve in relation to these two holes will vary the pressure within the bypass and internal passageways helping to regulate the mixture at the very lowest of throttle settings. (Figure: 5) During overhaul, failure to insure that all of these passageways are open and free from contamination will inevitably result in an engine that idles poorly.

Troubleshooting: the idle circuit and its effectiveness occurs from idle, up to about 25% throttle setting. (Figure: 6) This also shows that the jet needle and the needle jet have some effect down as low as 15% throttle setting. If the engine is running poorly at idle, but improves as the throttle is advanced passed the 15% throttle setting and then runs properly from 25% up through the mid-range and beyond, this would be an indication that the problem is related directly to something within the idle circuit. An engine that will not run at idle, but will run with the application of choke is an indication the idle circuit is running lean. The most common, and probable cause, is that the idle jet has a blockage. It is not uncommon for old fuel to evaporate leaving a film or obstruction in the orifice for the idle jet. Remember that the idle jet used on the Rotax 912 is .35 mm. That is about the thickness of a business card and is very easy to become blocked. Replacing the jet with a new jet, or even cleaning the old jet is the easiest way to troubleshoot. But remember, if the idle jet has become blocked with debris, the more important question is what caused the blockage and why and how did it occur? Most of the time when we find "junk" in the Idle jet, we are concerned with how it got there. The standard procedure would normally include flushing the fuel tanks, replacement of fuel lines, and replacement or cleaning of the fuel filter. If contamination is present, and you simply clean the jet without addressing

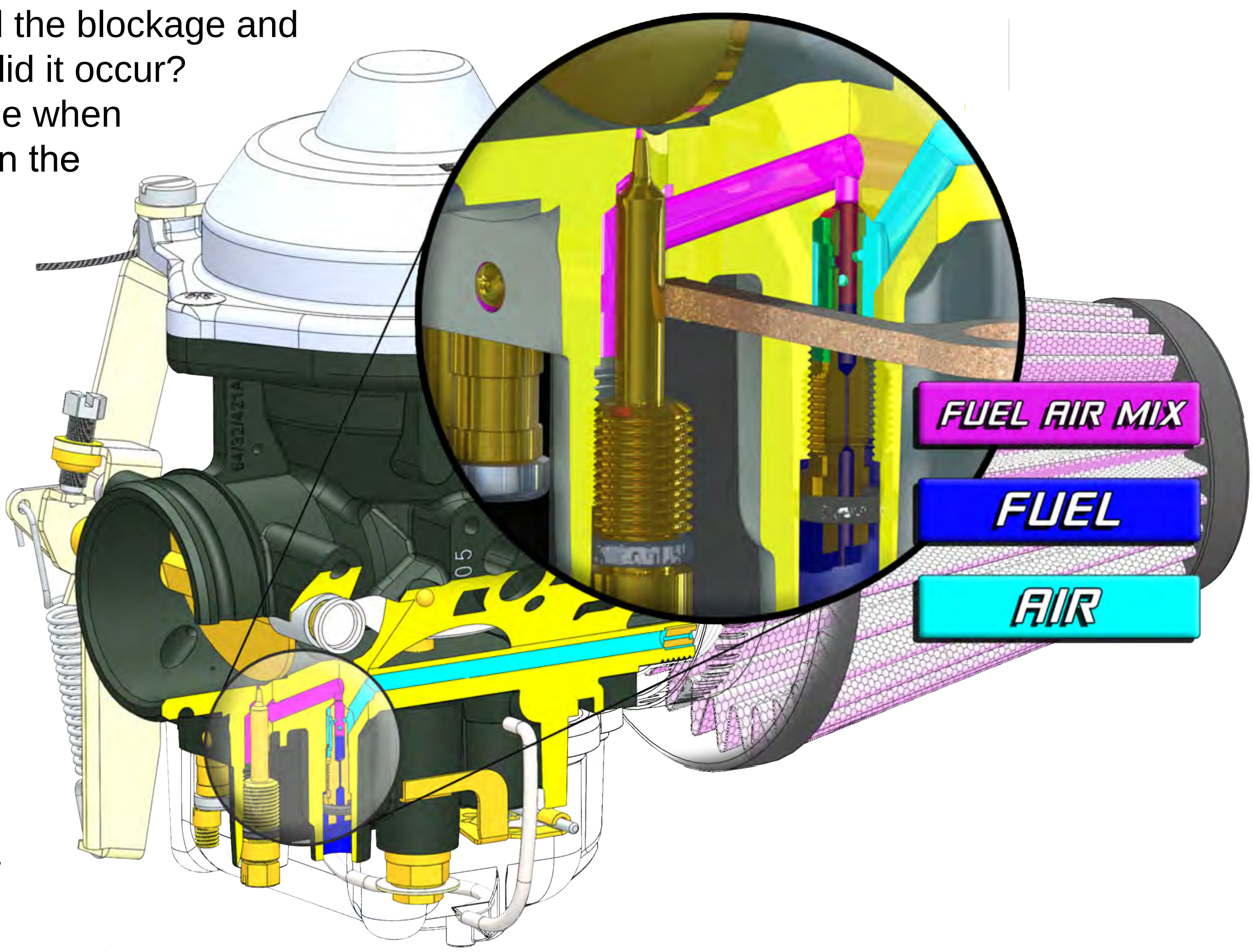

Figure: 4 Idle Circuit Passages Cut-away the root cause of the problem, it is likely to re-contaminate in short order.

If the engine is running rich at idle, there are several culprits that may be contributing to the problem. However, there are only two areas that usually affect a rich mixture at idle only. Improperly adjusted idle mixture screw or blocked idle air jet. If the engine is running rich at throttle settings other than idle, it probably has nothing to do with the idle mixture screw or the idle air jet. The idle air jet can be inspected visually for contamination, or by blowing compressed air through the idle jet. This is normally done with the carburetor disassembled and on the work bench. The adjustment of the idle mixture screw can be set to the settings specified in the "Bing" manual, or if you have a Rotax engine, the Rotax maintenance manual also specifies the settings for your particular engine. For most engines utilizing the CV carburetor, the setting for the idle mixture screw is 1.5 turns out. This means that you screw in the idle mixture screw until it makes contact with the carburetor body, then turn out or "counterclockwise" 1.5 turns. If you find that you need to adjust it different from the "book" settings in order for it to operate correctly, there is probably something else that is askew. Keep in mind that there are literally thousands of Rotax engines operating with stock jet settings. They all work perfectly. We have never seen a Rotax engine that needs to be set up differently than the recommended settings. The engines are identical. As such there is no reason that one engine would need special settings. If you find a condition where it appears that you need a different set up from stock, it is usually a symptom of a larger problem. The engines work as a

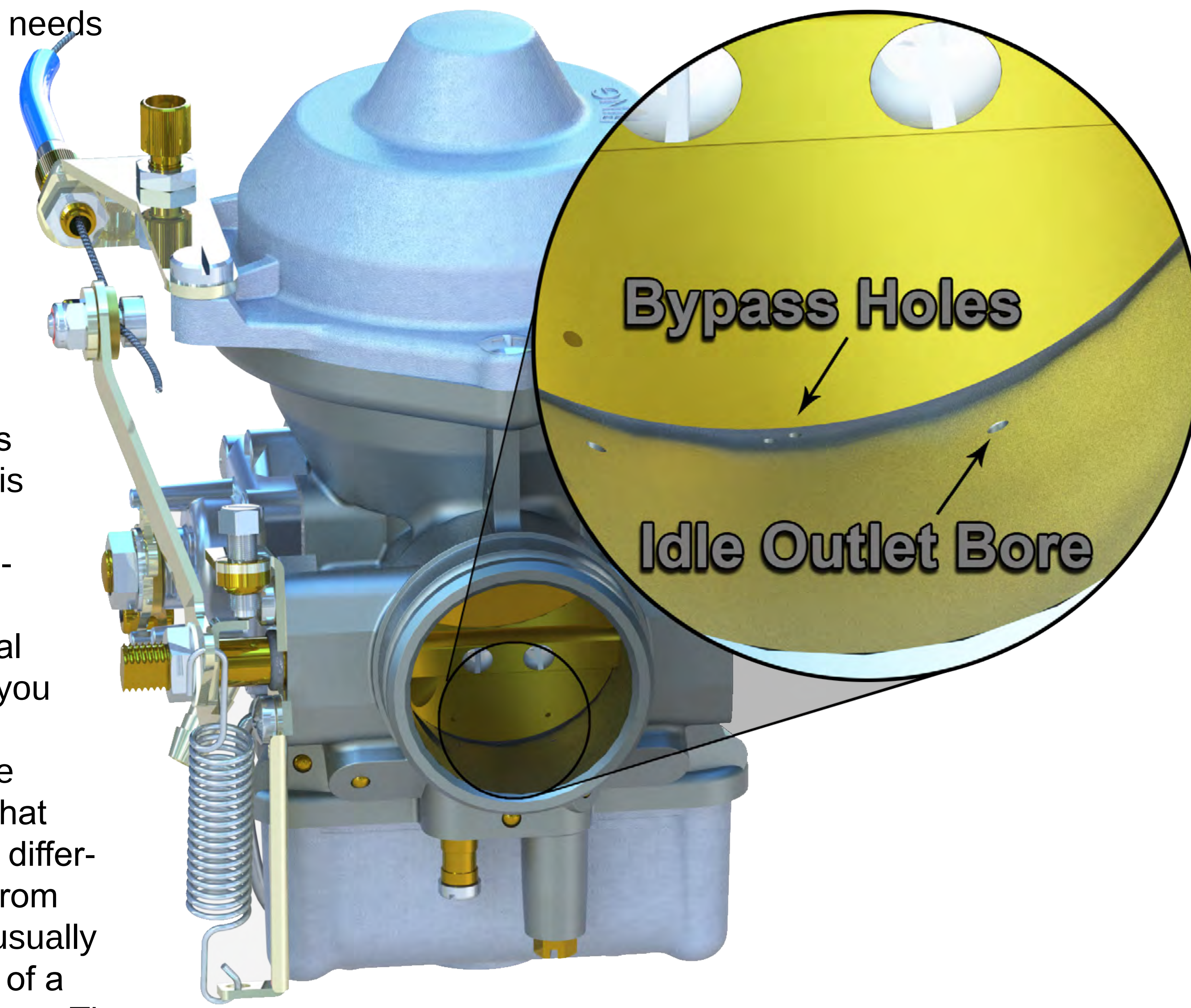

Figure: 5 Idle Outlet Bore and Bypass Holes symphony of different sub systems, all working in harmony with each other. The subsystems within the engine and carburetor cannot be isolated from the bigger picture. For example, doing carburetor synchronization on the engine without first insuring the idle mixture screws have been properly adjusted is a waste of time. Making adjustments to one subsystem has an affect on all other systems. The good news is, once you understand the subsystems within the carburetor, the ability to keep them operating correctly is really quite easy and simple.

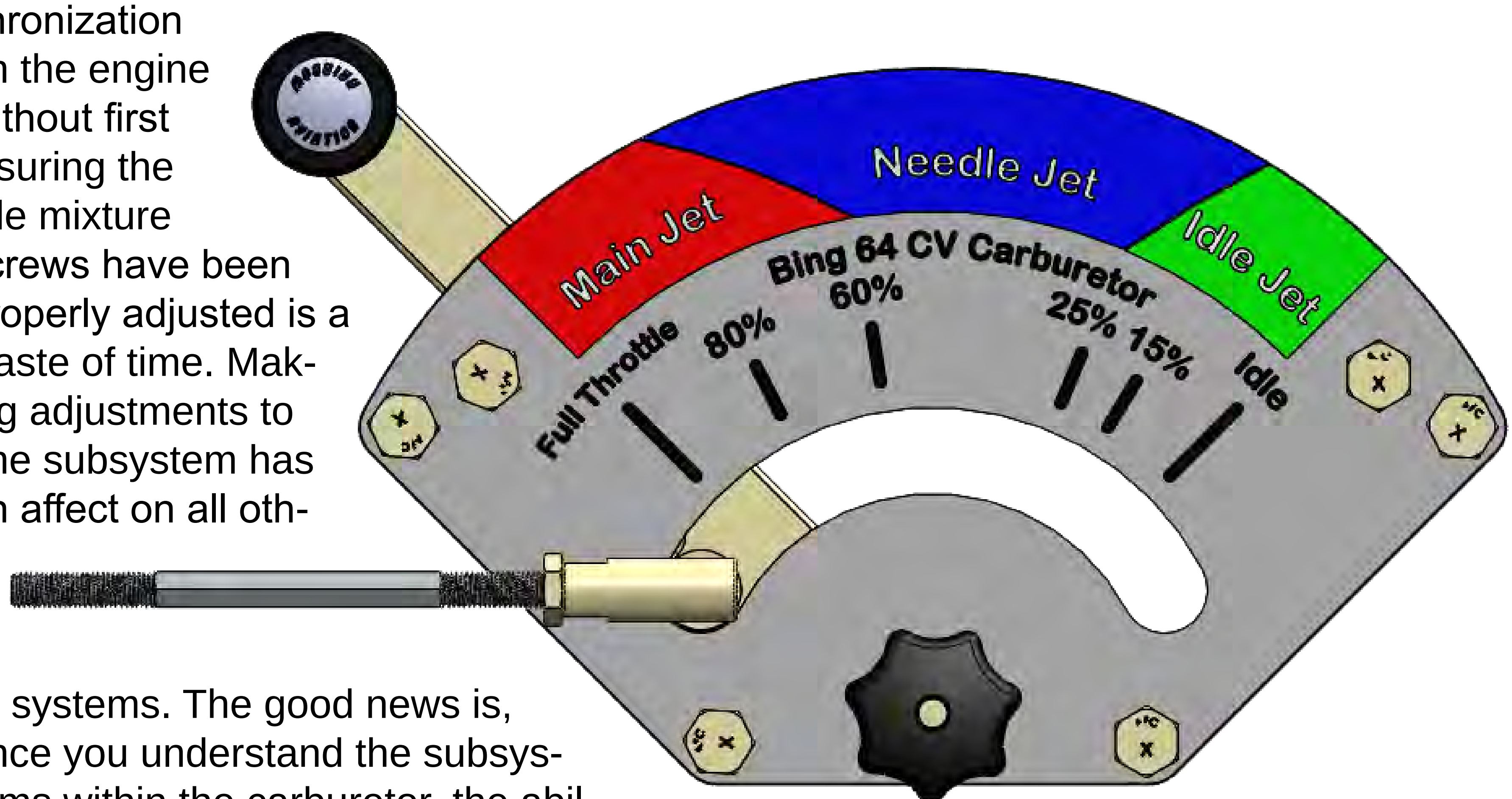

Figure: 6 Jet Effectiveness Vs Throttle Position

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In last couple of articles, we talked about the ability to utilize a borescope in identifying detonation or pre-ignition problems within a cylinder. A pilot, who stopped by the office while we were working on the detonation article, had several questions about detonation. This, in turn, led into a completely different discussion about using a borescope to identify problems. We showed him some pictures we had collected using our newest borescope. This snowballed into a trip out to the hangar for show and tell where we opened one of the bottom drawers labeled “Inspection Tools” which revealed a plethora of borescopes from our last forty years in the aviation business. Some of these borescopes appeared to be estranged from some aviation historical museum, while others look like they may have been dropped off by some NASA inspection team. By the time we had concluded our discussion, we were all in agreement that an article talking about the use of these modern day borescopes would be unavoidable.

Although, a lot of aviators believe the “bore” in borescope refers to the bore of a engine cylinder, the origin of the term actually goes back to World War II when weapons manufacturers used them to inspect the interior “bore” of large gun barrels. The original borescopes were relatively primitive, consisting of a rigid tube and optical lenses that allow the observer to get a close-up view of an internal passageway from a substantial distance much like a telescope. Since those early days of the borescope, there has been literally thousands of different designs, morphing from the original rigid, fixed distance designs, into more usable instruments incorporating a myriad of different capabilities including camera and video capability. Early on, the borescope was considered a luxury. They were relatively expensive and could only be afforded in the most important of circumstances. The endoscope was the medical industry’s equivalent of the borescope. This device revolutionized the medical industry by allowing doctors to get a firsthand look inside of the human body without invasive surgery. Even though we had several rigid borescopes for inspecting cylinders, it really changed our perspective on the capability of these

Figure: 1

instruments the day that our local doctor brought his very expensive, high quality, endoscope from his office for us to use in inspecting the wing closeout on his Lancair IV-P. While there was much laughter and joking about the efficacy of this particular instrument transitioning its usefulness in both the human body and the workshop, it was our first exposure to an instrument that could turn corners, adjust lighting, adjust focus, and extend far into the "bowels" of the aircraft wing. It really provided an additional level of capability not possible before. Unfortunately, the cost of these tools at the time was something not afforded the average shop. And, we must admit, there were a few other "emergency" occasions that we asked to use the tool again. It wasn't until many years later that the cost and capability of the borescope was really changed by advent of digital technology.

Once the borescope hit the mass-market, the product cost started dropping dramatically. Large tool manufacturers started offering digital borescopes with camera and video capability for use around the home and by contractors for inspecting all manner of things from interior walls, and sewer lines, to HVAC systems. (Figure: 1) Many of these tools, now renamed as inspection cameras, became very useful for aircraft inspection. Many of them had extensions that made it possible to access even the most remote parts of an aircraft. Initially, the cost was in the $100 to $200 price range. However, even the cost of these units continue to decline in price as well as increase in their capability.

In the last five years or so, we have seen a completely new entry into the field: the borescope camera that adapts to a smart phone. There are literally dozens of manufacturers making these smart phone enabled borescope cameras. By utilizing the computing power of the smart phone, they are able to manufacture just the camera end of the borescope by placing the micro CMOS sensor (the device used to collect the digital picture) directly at the end of the borescope and transmitting that signal back through a conventional USB connector into the phone. Because of the proliferation of these camera components and literally millions being used around the world, the cost has plummeted, making the average cost of one of these borescope units from $20 to $40. (Figure: 2) Many of the smart phone borescopes have wireless capability making them easy to manipulate in close quarters inside the aircraft while watching the video screen on your phone from a more comfortable

Figure: 2

location. Most of these types of borescopes working through your cell phone allow for capturing pictures as well as video of your inspection. Even if you can't easily watch your phone and manipulate the inspection camera at the same time, you can come back later, download the video onto your computer, and conduct your inspection with a large screen and the capability of pausing and reviewing your subject matter.

As if all of this new tech wasn't enough, last year at AirVenture 2017, we became intrigued by one of the vendors selling the latest adaptation to all of these innovations. Vividia Technologies has taken this basic concept to an entirely new level by providing a fully articulating head. (Figure: 3) When we saw this, we had to have one. And after researching all the different models that they have available, we elected to purchase the VA-980. This borescope appeared to have the most versatile application for aircraft. The biggest problem associated with all the consumer borescopes has always been the limited amount of flexibility when trying to position the camera in such a fashion as to view or take a picture of a very particular spot when in a confined space. Of course, one of our most common usages, is for inspecting cylinders. When using the traditional borescope, or many of the new consumer borescopes, there is a limited ability to be able to adjust the angle of viewing, usually less than 30°. Even the adapters that can be fit to the end of the borescope in order to change the angle of viewing can be limiting because of their fixed location once inserted into a spark plug hole, for example. We may be able to see one side of the valve, or valve seat, but getting around to the opposite side still remained nearly impossible. When working with our VA-980

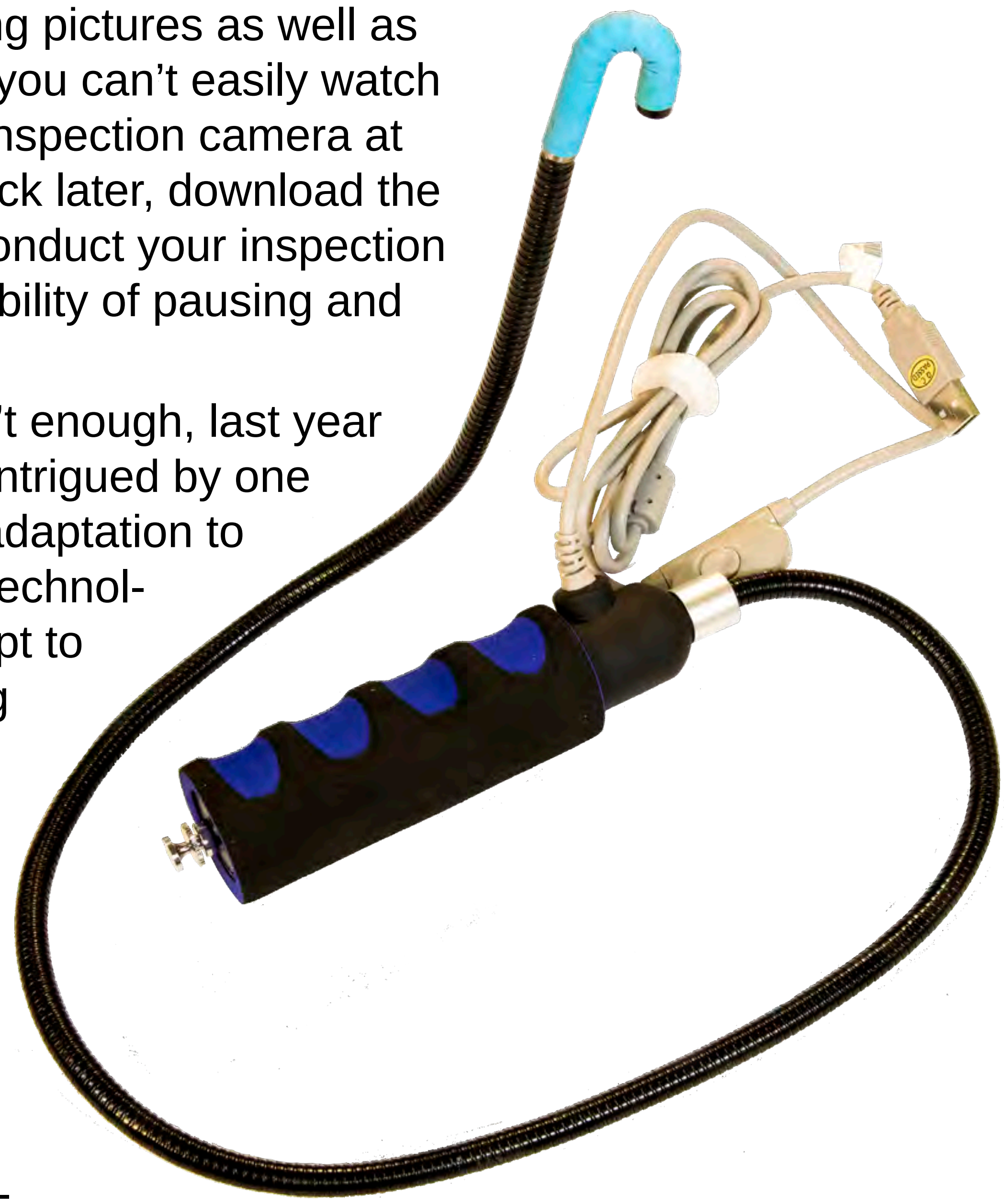

Figure: 3 Vividia VA-980

Figure: 4

articulating borescope, our ability to “take a walk” around the entire inside of the cylinder becomes possible. The ability to insert the camera through a spark plug hole and then reverse the lens 180° really makes a huge difference and is just what the doctor ordered when it comes to inspecting a cylinder. We were recently conducting a borescope inspection on a Rotax 503. With the borescope inserted through the spark plug hole, to demonstrate its capability, we took a selfie from inside the engine looking out through the exhaust port. (Figure: 4)

In our shop, we use a completely digital record-keeping system and now incorporate the pictures and video from borescope inspections directly into the aircraft records. Having the ability to send pictures and video directly to a customer can help in the communication process when dealing with a problem on their aircraft. We have really become dependent on these tools during an annual inspection. The days of standing on your head with your feet sticking out of the cockpit utilizing a flashlight in a mirror under the instrument panel are over. We can sit in the cockpit with our laptop and borescope and explore even the most inaccessible areas. With these new tools at our fingertips, we have significantly increased our troubleshooting and inspection capability. If you are an aviation maintenance technician, you may want to spend a little extra for the more professional articulating type of borescope. And although limited in its resolution (640 x 480), just being able to place the camera where you want it is invaluable. For the budget minded, the $25 smart phone borescope adapter, even with its viewing limitations, makes it an addition to your toolbox that we think you will find surprisingly useful.

Burping The Rotax 912

If you're interested in a spirited discussion, or a heated argument, I would recommend that you bring up the subject of burping the Rotax 912 engine at your next EAA meeting. Let's start off with the definition of burping. When we talk about burping the Rotax 9 series engines (912, 912S, 912IS, and 914) we are essentially talking about the method by which we remove all of the oil from the crankcase of the engine and send it back to the oil tank. The Rotax 912 utilizes a dry sump oil system. However, the dry sump system used in the Rotax is a little different than what we would typically encounter. Even Wikipedia identifies a dry oil sump system as a "system that uses two or more oil pumps". Typically, one pump that sucks oil from the oil tank through to the oil pump and subsequently supplies pressurized oil to the engine to lubricate all of the engine components, and a secondary oil pump that collects the excess oil in the bottom of the engine and pumps it back into the oil tank. One of the great advantages of having a dry oil sump system is the ability to remotely locate the oil tank. This allows the design of the engine to be very compact in comparison to an engine with a wet sump. Typically, in a wet sump system the "oil tank" is co-located within the engine, positioned at the bottom of the crankcase, so that all of the oil that is run through the engine oil system simply drains back into the sump (oil tank) where the main oil pump suction tube is located. The overall frontal area for a wet sump engine of the same size can easily be increased as much is 20%. The primary downside of a dry sump engine is, of course, that we have two oil pumps. And with two oil pumps comes an increase in the maintenance, weight, complexity, cost, and the potential for an oil system failure. Simple is always better.

> ***"In typical Rotax fashion, even the method by which the oil is introduced back into the oil tank is ingenious. The design is undoubtedly tied to the rich Barvarian culture which has perfected the art of drinking beer.."***

Rotax, in their infinite wisdom, devised a method by which they could take advantage of the dry oil sump system without all of the downsides of a typical dry sump system. The Rotax engine utilizes a dry sump system with only a single oil pump to suck oil from the bottom of the oil tank and pump it through the engine. (Figure: 1) The ingenious way by which the oil is returned to the oil tank is essentially by locating the engine crankcase breather tube on the bottom of the engine and allowing crankcase pressure to push the oil back into the oil tank. All engines create crankcase pressure. This is simply a result of the pressure within the combustion chamber leak-

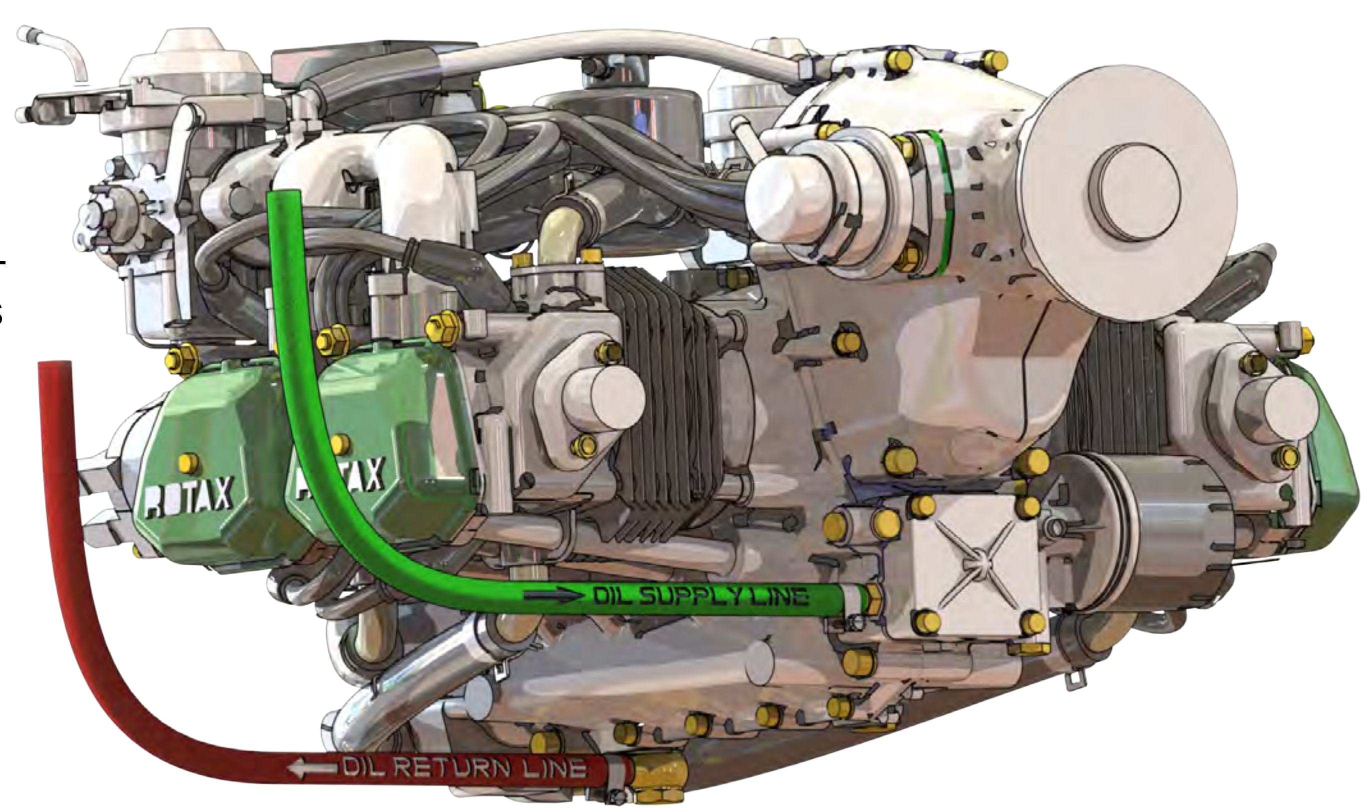

Figure: 1 *Engine Oil: Supply Line and Return Line* ing past the rings during the compression stroke. Even without the engine running, as the piston approaches top dead center, on the compression stroke, the pressure within the combustion chamber continues to increase until top dead center is reached. During this process, even on the best of engines, there is some air leakage around the rings, and particularly at each of the ring end gaps. This leakage of air from the combustion chamber, past the rings, into the engine crankcase is what supplies the crankcase pressure that forces the oil back into the oil tank. During normal engine operation with the engine running, each piston is leaking a small amount of air during the compression and especially the power stroke. As the oil pump draws oil from the oil tank and into the engine, through the passageways, it eventually finds its way back to the bottom of the crankcase where the return line to the oil tank is located. In typical Rotax fashion, even the method by which the oil is introduced back into the oil tank is ingenious. The design is undoubtedly tied to the rich Barvarian culture which has perfected the art of drinking beer. The oil, just like beer, has a tendency to foam when simply dumped into a container. The technique of placing the tap against the edge of the glass to reduce foaming is also used in the oil tank. As the oil enters the top of the oil tank, the line returning the oil is positioned against the side of the oil tank at an angle to allow the reintroduction of the oil as smoothly as possible, reducing its tendency to foam. (Figure: 2)

Now that we have a basic understanding of how the oil system functions, let's apply this to the principle of burping. Before we fly, we need to be able to check the oil quantity. However, this isn't quite as simple as simply pulling out the dipstick and checking the oil level. We have oil in the oil tank, however, we also have oil in the engine. As the aircraft sits, the oil from the oil tank can slowly leak from the oil supply line into the engine. This leaves the oil quantity within the oil tank low. In order to get an accurate accounting of the total amount of oil in the system, we need to return the oil from the engine back into the oil tank. By turning the propeller in the normal direction of rotation (and only in the normal direction of rotation) we can build pressure within the combustion chamber which will leak past the rings and pressurize the crankcase returning any oil back into the oil tank. When we have introduced enough air into the crankcase to displace all of the remaining oil, any additional air will also exit through the oil return line. With the oil cap removed from the oil tank, we can hear that air exit from the crankcase, through the oil return line, and into the oil tank. The sound that the air makes as it exits the oil return line is a very distinct "burp" or "gurgle". Because the oil return line is located on the bottom of the engine, all of the oil will be forced through the return line before any air can enter. By default, this is an indication that most of the remaining oil has been removed from the bottom of the engine crankcase and is now in the oil tank. At this point, you can check the dipstick to get an accurate reading of the oil quantity. We often hear 912 operators complaining that seems to take forever for their engine to burp. And they'll often complain about having to pull the propeller through 40 to 50 blades in order to get the first indication of a burp. Frequent-

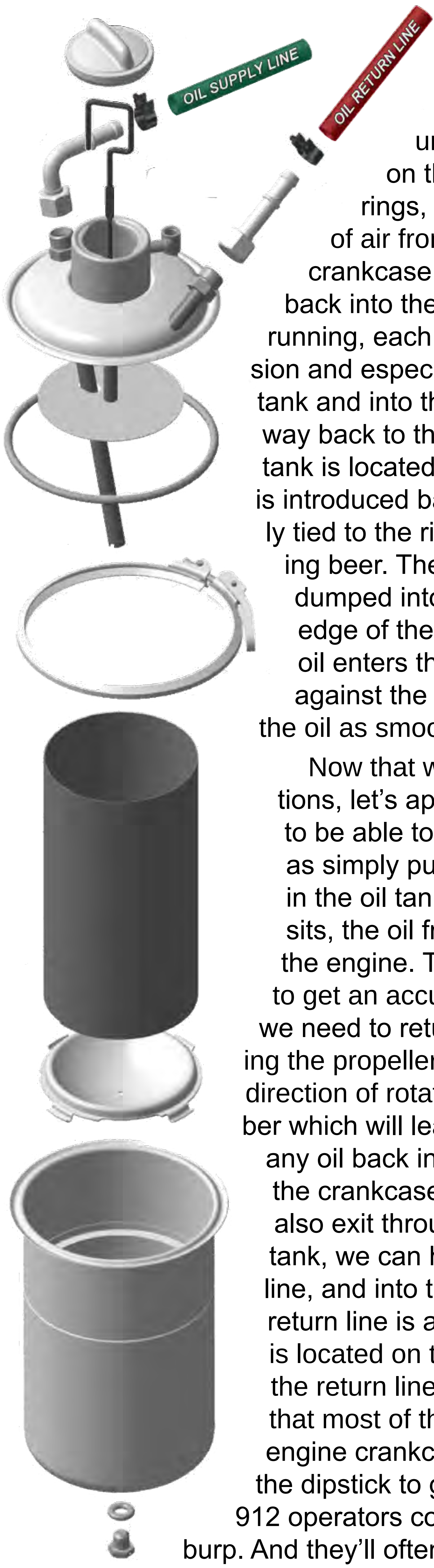

Figure: 2 Oil Tank Assembly

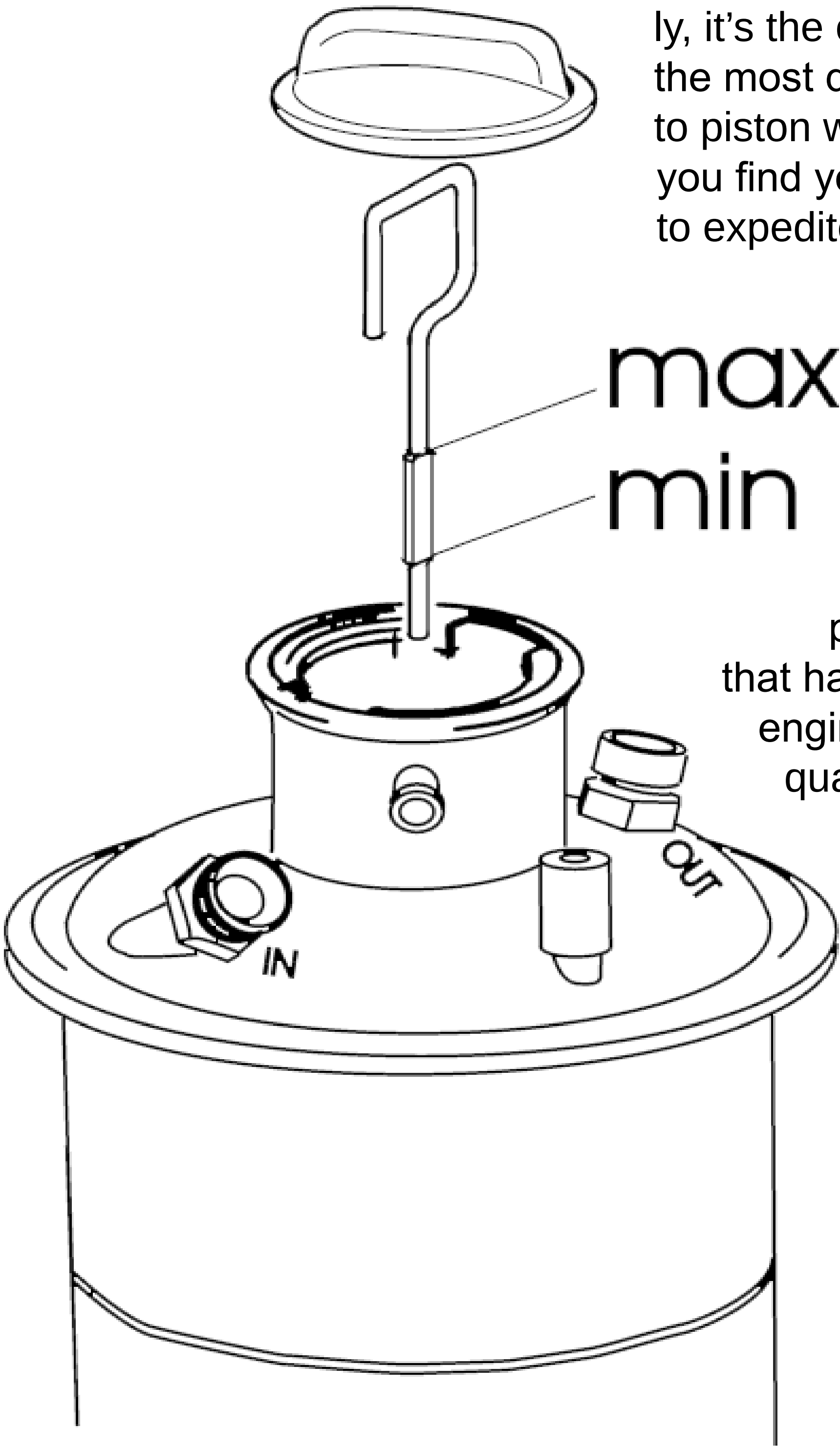

Figure: 3 Dip Stick

ly, it's the owners of the newer airplanes that seem to have the most difficulty. This is pretty easily explained. The cylinder to piston wall clearance on a Rotax 912 is extremely tight. If you find yourself pulling the propeller through quickly in order to expedite the process, the pressure within the combustion chamber rises and then instantaneously dissipates. The volume of air that has a chance to leak past the ring end gap is very small. This requires that you pull the propeller through many, many, times. If you simply rotate the propeller blade until you have one of the pistons at top dead center, then wait a few seconds for the air to bleed past the rings, you will find that the volume of air that has entered the crankcase is much greater. After the engine has been running, it is very easy to check the oil quantity accurately. During normal engine operation the oil is continuously forced back into the oil tank. The only additional oil that you will have to move from the crankcase to the oil tank is any oil that is dripping off of the internal engine components and pooling at the bottom of the case. When the engine is cold it will naturally be more difficult to move the oil back into the oil tank simply because of its high viscosity. It is also normal to see a slightly less amount of oil on a cold engine versus an engine that has just been running. This is primarily due to the high viscosity oil sticking to internal engine parts. The argument about checking oil resides around the concept of checking oil after its hot being more accurate and easier to check, versus the necessity to check oil before a flight as an integral part of a proper preflight inspection. We favor the check before every flight and after every flight procedure. This will ensure that you have the proper oil level before takeoff, as well as giving you a really accurate reading at the end of the flight. This procedure can also alert you to the possibility of high oil consumption or an oil leak. The oil level should be in the upper half (between the "50%" and the "max" mark) and should never fall below the "min" mark. Prior to long flights, oil should be added so that the oil level reaches the "max" mark. (Figure: 3) Oil consumption on the Rotax 9 series engines is notoriously nonexistent. We recently did a flight from the upper Peninsula of Michigan to Northern California in a Rotax 912 powered Rans Coyote. The oil level was down only about 1/8" from the start to the end of the flight. Checking your oil level both before and after each flight should give you a broad overview of the condition of many internal engine subsystems. Knowing that everything is operating consistently will leave you with that warm and fuzzy feeling that makes the difference between a happy, comfortable flight, and a flight that is fraught with concern.

Carol and Brian Carpenter are owners of Rainbow Aviation Services in Corning, California.
For more Information visit www.rainbowaviation.com

Carburetor Synchronization

With the proliferation of the Rotax 912 80 hp and the Rotax 912S 100 hp engines, the topic of carburetor synchronization has come to the forefront. Until about the 1980s, the popularity of Continental and Lycoming engines dominated the general aviation market, these engines used a single carburetor providing for a single source of air and fuel to the cylinders. The use of dual carburetors was primarily relegated to the area of the two-stroke ultralight market. And, even with these engines, the process of carburetor synchronization was quite simple and reliable. However, with the popularity of the Rotax 9 series engines, it has become important to understand a little bit more about how the induction system works on this amazing little powerhouse. This understanding is important not only from a maintenance standpoint, but from a pilot's perspective as well.

The Rotax 912 is essentially two engines connected to a single crankshaft and gearbox with both the left and right sides of the engine having their own independent carburetor, ignition, and exhaust system Figure: 1. As you might well imagine, having two engines trying to run a single propeller requires a bit of choreography between the right and left side of the engine in order to make things run smoothly. Most of us, who have spent a considerable amount of time in the air, can remember a time when one of the cylinders on a

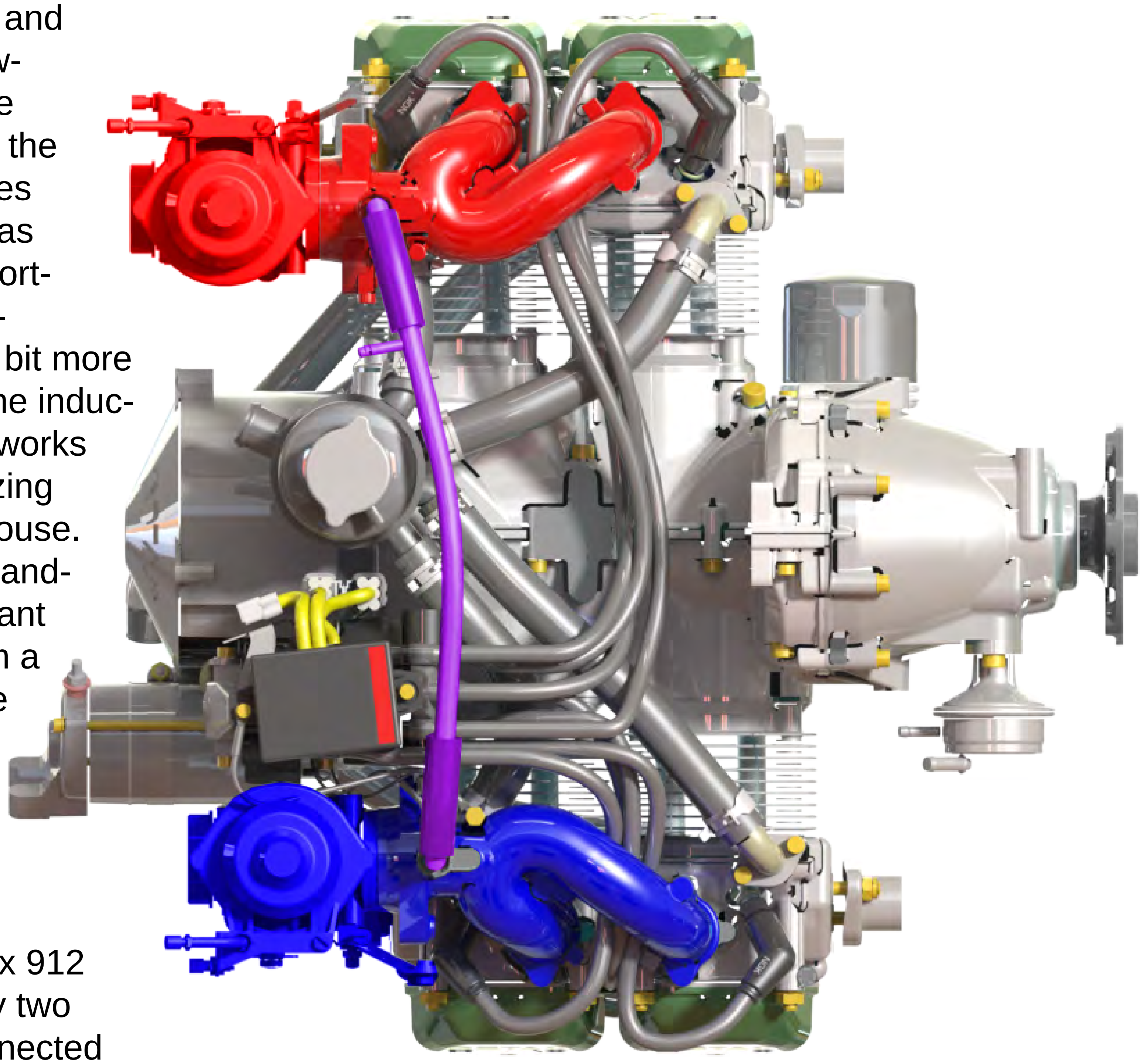

Figure: 1 The Rotax 912 is two separate engines connected to a common crankshaft

Figure: 2 *Clamping off the crossover (Balance) hose*

four-cylinder engine just quit firing, maybe from fouled spark plugs, or a plugged fuel injector. Regardless of the source, if you have ever lost a cylinder, it likely got your attention. Now imagine losing two cylinders. This is nothing short of an all-out assault on your engine and airframe. The shaking can be so violent that the fear of the motor departing the airframe becomes a realistic concern. With an engine like the Rotax 912, which has the right and left side induction systems isolated from each other, you can see the potential hazard with having one throttle wide open and the other at idle. The resulting reaction of the engine would be similar to the scenario of losing two cylinders in our previous example. In fact, we now train pilots differently in a Rotax powered aircraft by teaching them to advance the throttle to full throttle in the event of a violently shaking engine. The reason for this is that on most Rotax powered aircraft the throttles are spring-loaded to the full throttle position. As a result, in the unlikely event of a throttle cable failure, pulling the one remaining throttle cable back to idle when the engine starts to shake just exacerbates the problem. By advancing the throttle to full throttle, it allows the throttle springs to bring both carburetors to the (same) full throttle position. This allows the engine to run smoothly and the aircraft to be flown to the nearest airport where the engine can be shut off for a dead stick landing, a better scenario than losing the engine power entirely. Theoretically, at full throttle the carburetors are perfectly synchronized by the throttle arms hitting the full throttle stops simultaneously.

So we've identified that the Rotax 912 is basically two engines running in synchronicity at full throttle. Having one throttle cable adjusted in a slightly different position (let's say 1/8" of extra cable), compared to the other throttle cable, at full throttle

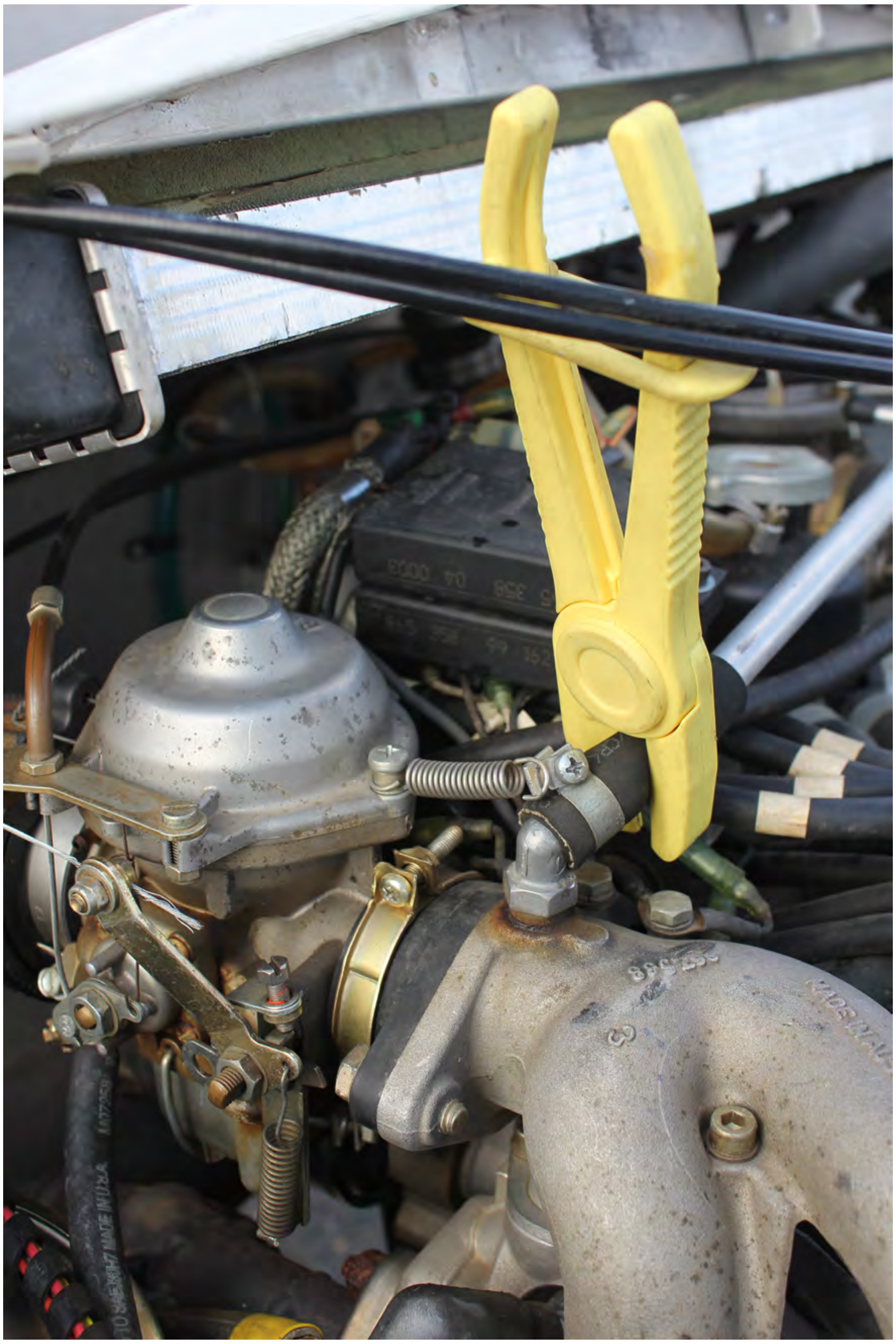

Figure: 3 Clamp Pliers

would result in only a miniscule differential in the manifold pressure of the two intake manifolds. However, if the throttle arms are in the idle position 1/8” difference in throttle cable length would result in a massive pressure differential between the two intake manifolds. And as a result, the engine would run extremely rough. At idle a very small adjustment makes a significant change in the pressure differential. And as we open the throttle wider the pressure differential between the two manifolds decreases. The most important synchronization point is at idle and just off idle.

A balance tube has been designed into the engine shown in purple in Figure: 1. This is a tube which runs from one intake manifold to the other. The theoretical basis for this is that if one throttle is slightly further open, and as a result has a slightly higher manifold pressure, the fuel/air mixture will be diverted through this crossover tube to the other intake manifold equalizing the manifold pressure. When both throttles are open exactly the same amount and the manifold pressure is identical there is no flow from one side to the other through the balance tube. And when there is a significant imbalance or mis-synchronization the flow through the balance tube is substantial. Understanding this has allowed us to develop a quick and simple field test to identify engines with poor synchronization. By taking a pair of hose clamp pliers and momentarily blocking off the rubber hose connecting the balance tube to the intake manifolds while the engine is running we can identify a poorly synchronized engine Figure: 2. If we block off the balance tube and the engine continues to run smoothly, there is little flow from one side to the other. However, if we block off the balance tube and the engine shakes a great deal, it is an indication that the engine is in dire need of proper synchronization. On one occasion the shaking was so bad after blocking off the crossover hose that the carburetor was shook loose from the intake manifold.

Figure: 4 Synchromate II installed into manifolds

The absolute best vacuum hose pliers to use for this operation, ironically can be obtained from Harbor Freight. They make a very low cost set of plastic vacuum hose pliers with a locking device. The jaws on the plastic vacuum hose pliers have a very nice rounded "V" section that fits perfectly in between the cross-over tube and the intake manifold Figure: 3. Simply pinch the hose between the pipe and the manifold fitting without pinching the aluminum pipe. Now, as you might imagine, this simple test is in no way a substitute for doing a proper carburetor synchronization.

Some of the characteristics associated with mis-synchronized carburetors include: Overall vibration causing wear and tear on the airframe and engine. Rough running at idle, too low of idle speed, including engine stopping during final approach. Excessive wear on the gearbox resulting in an increase in the amount of steel both in the oil filter as well as on the magnetic drain plug. Troubles with the needle and seat within the carburetor seating properly, particularly at idle. This causes excessive fuel in the float bowls and a rich mixture. The rich mixture, in turn, makes the engine run rougher exacerbating the shaking problem.

Rotax provides a fairly comprehensive set of instructions for proper carburetor synchronization in the line maintenance manual, downloadable from the Rotax website (<http://flyrotax.com/>). However, the myriad of different throttle linkage systems used throughout the light sport industry require that you extrapolate on to the synchronization procedures and adapt them to your specific type of throttle actuation system. No matter how your linkage system is designed, the basic procedures involve installing a manifold pressure monitoring system into each of the two intake manifolds and then adjusting the carburetors to achieve an identical manifold pressure both when the throttle is at "idle" as well as just "off idle". We use a Synchromate II Figure: 4. This is a digital synchronization tool built specifically for the Bing Carburetors and has the added advantage of allowing the synchronization of the tool prior to each use. By disconnecting the balance tube from the engine and attaching the synchronization tool into each manifold, we can measure the differential pressure between each intake manifold. On the Synchromate II, when the digital bars are in the center position Figure: 5, the pressure in each manifold is equal. Bar movement to either side will indicate the manifold with the lower pressure Figure: 6. The challenge becomes understanding your throttle linkage system. The system should have a physical idle throttle stop normally at the throttle, which should be making contact simultaneously as both throttles hit the idle RPM adjustment stop, this needs to occur while maintaining proper idle rpm and perfect synchronization. Now, if that isn't enough, as you advance the throttle to move the throttle arm off of the idle RPM adjustment stop, the cable adjustment now controls the synchronization. Ironically, if adjustment of the cable is necessary in order to maintain synchronization in the off idle position, it will inevitably screw up your throttle cable position in relationship to the physical idle stop at the throttle. This, in turn, will allow the throttle to be pulled against the idle stop at the carburetor. Excessive force against the idle stop can cause the light weight idle stop on the Bing carburetor to bend. This, now, causes the idle synchronization to be screwed up and as a result, the entire synchronization and adjustment process needs to be started over. If you are new to this process, it can be rather frustrating. Our recommendation is that you use an experienced LSRM (Light Sport Repairman with a Maintenance Rating) experienced with the carb synchronization process to help you through the first synchronization.

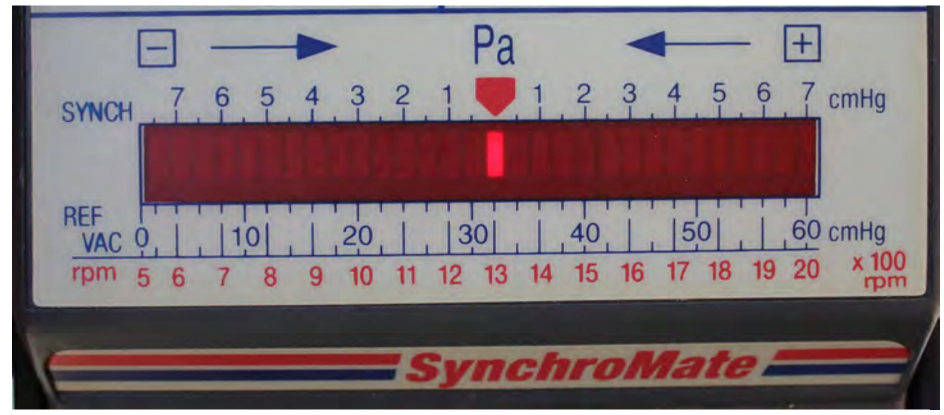

Figure: 5 Properly synchronized carburetors

Once you become familiar with your particular airplane, have the throttle linkage set up correctly, and you understand how it works, the system is rather simple and bulletproof. Most of the problems we see related to carburetor synchronization are simply a lack of understanding about how to properly set up the linkage in relationship to the carburetors, poorly designed throttle systems, or trying to synchronize worn out carburetors that need to be rebuilt. It is a waste of time to be synchronizing the carburetors if they are not set up and working correctly. The 912 and 912S Rotax engines are amazing products. Once you become familiar with the nuances of their maintenance and operation, you can't help but be impressed by the elegance of the design.

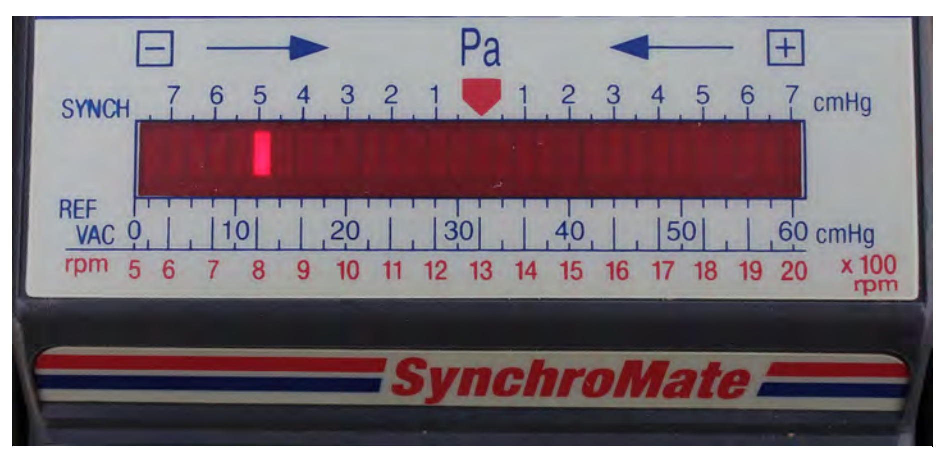

Figure: 6 Improperly synchronized carburetors

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The experimental aircraft world is certainly no stranger to the use of blind rivets. The "POP®" rivet is perhaps the most ubiquitous term when it comes to describing a blind rivet. But the "POP" in POP® rivet was just a brand name originated by the company USM. Today there are literally hundreds of different manufacturers producing blind rivets using this same basic concept. Although the blind rivet, in the past, had never been accepted as a standard fastening method for your average "spam can" (a term affectionately used to describe a type certificated aircraft of aluminum construction), there were exceptions. The Zenith CH 2000 was one of the first type certificated aircraft that used blind rivets for its primary method of construction. This aircraft, in part, paved the way for the acceptance of blind rivets in aluminum aircraft construction, and today, the vast majority of light sport aircraft which are manufactured from aluminum use the blind rivet assembly process. Perhaps the single biggest advantage of using blind rivets, is the the ability to fasten a structure together without access to the opposite side of the structure. That, coupled with the ability of an operator to conduct the entire riveting operation single-handedly, has significantly reduced the amount of labor necessary to assemble an aluminum structure. That being said, let's discuss some of the differences between a standard MS20470 AD solid rivet, a typical pop-type rivet, and the subject of the article, the CherryMAX®

Solid rivets have two primary advantages over POP® rivets when it comes to assembly of aluminum structures. The first, and prob-

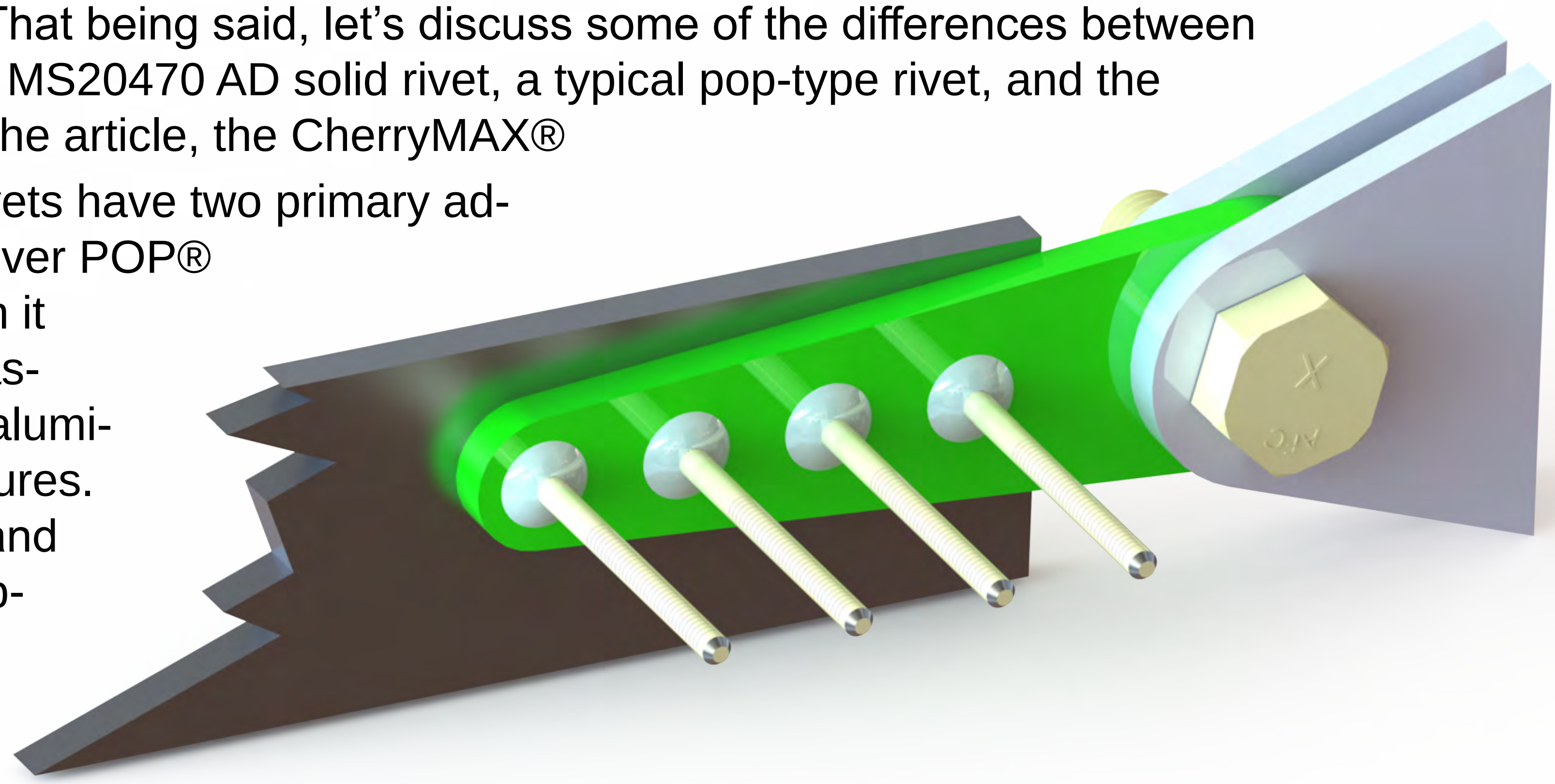

Figure: 1 *Hypothetical Structure*

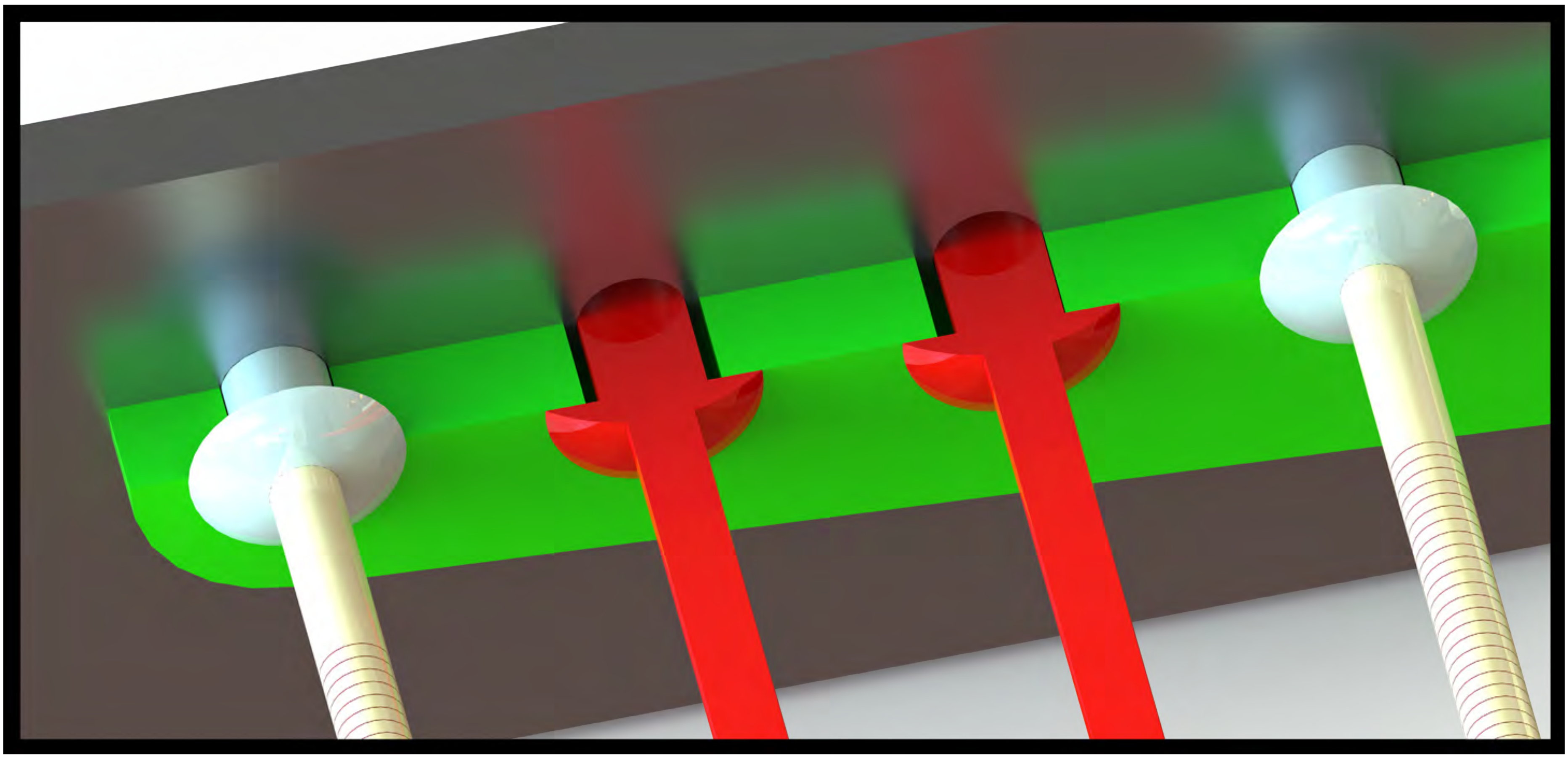

Figure: 2 *Hypothetical Structure Cut-A-Way*

ably most important, is the ability of a solid rivet to swell up and fill the entire drilled hole even if the rivet hole is not perfectly concentric or even of the correct size. In (Figure: 1) we have a hypothetical structure. A bolt capable of 1000 pounds sheer, and four rivets each capable of 250 pounds in single shear. (4 x 250 = 1000) a legitimate structural configuration. However, this configuration only has validity if each of the four rivets can carry their share of the load. From the outside everything may look "peachy." But what if we were to take a cross-section of the hypothetical structure and find that one of the rivet holes was oversized and perhaps another one drilled slightly off center. (Figure: 2) We would essentially be left with only two of the rivets carrying all of the load. The other two rivets contribute nothing to the transfer of load from the fitting to the structure. The only way that the two oversized holes could impose a load transfer would be after the initial two rivets had already been partially sheared off. This is obviously an untenable situation. A solid rivet driven with a rivet gun and bucking bar will swell up inside the hole allowing even the rivet holes with anomalies to be able to carry the intended load. When it comes to structures that are assembled

Dia. Dash No.	Diameter +.003 -.001
-4	.140
-5	.173
-6	.201
-8	.267

Figure: 3 *Oversized Cherry Max Rivets* with pop rivets, the integrity of that structure depend solely on the precision of the rivet holes. The RV-12 is an example of an aircraft using CNC match drilled technology to obtain near-perfect alignment of all rivet holes. This provides for precision so accurate that it virtually eliminates the necessity for deburring and a final assembly that results in each rivet installation with that necessary “perfect fit”. The CherryMAX® rivet was designed as a replacement for the solid rivet. However, the CherryMAX® rivet, much like the pop rivet, does not swell internally. To create a blind rivet capable of replacing a solid rivet,the issue of imperfect holes had to be addressed. As a result, the CherryMAX® rivets come, not only in nominal sizes, but also in oversized diameters. (Figure: 3) This allows for a hole to be drilled slightly oversized without the dramatic jump associated with the next size rivet.

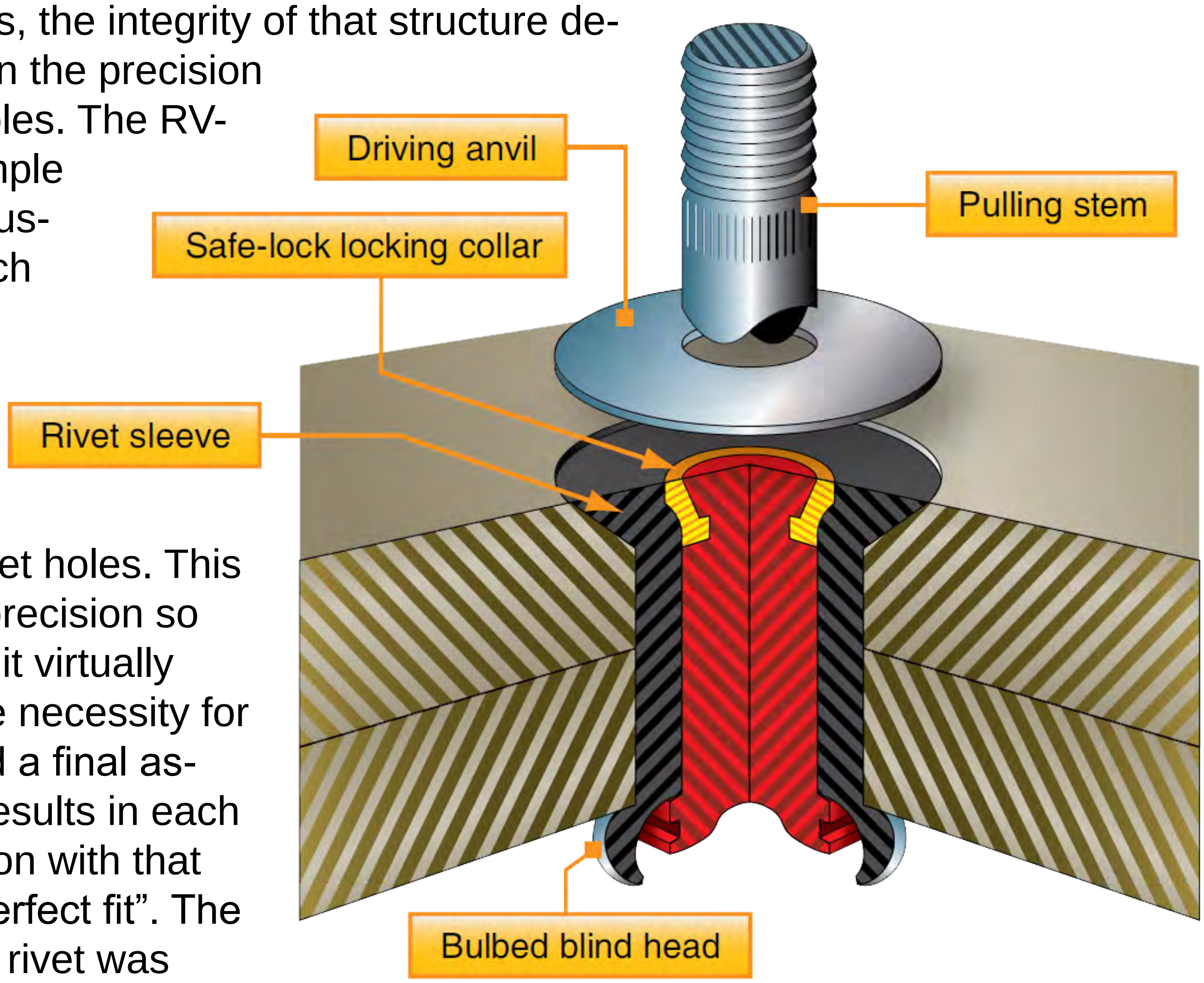

Figure: 4 The CherryMAX® Rivet Installed

The second advantage of a solid rivet is simply its sheer strength in comparison to a blind rivet, in particular a blind rivet with the center stem missing. Most of the aircraft manufactured with blind rivets, utilize rivets that have a center stem used for creating the bulb on the end of the rivet, which breaks

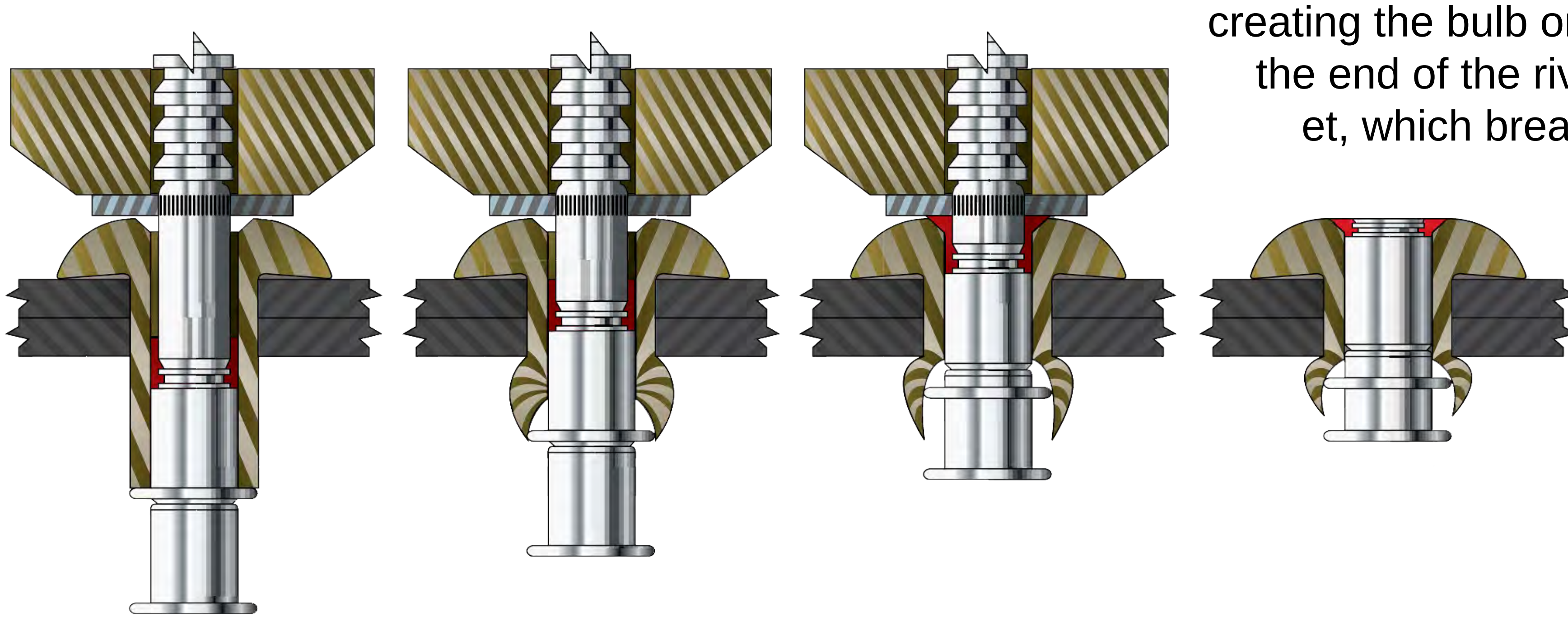

Figure: 5 The CherryMAX® Installation Sequence free from the core leaving the rivet hollow. And, as you might imagine, a hollow rivet does not possess the same shear load capability as a solid rivet. 1/8 inch diameter MS20470 AD rivet as a single sheer strength of approximately 384 pounds whereas an 1/8 inch aluminum pop rivet with an aluminum mandrel has a single sheer strength

Figure: 6 CherryMAX® Grip Guage

of around 120 pounds. These rivets are very lightweight and are typically more than adequate and even preferred on many of the light sport aircraft where the utilization of thin sheet-metal requires a much closer rivet spacing. The RV-12 is an example where more than 10,000 of these rivets are installed in the final assembly. Many manufacturers have opted to utilize stainless steel pop rivets with a stainless steel stem. These 1/8 inch rivets have a single sheer strength of around 420 pounds. Aircraft like the Sonex and many european manufacturers utilize these type of rivets extensively. The CherryMAX® rivet has solved the compatibility with the solid rivet problem by creating an alloy steel stem that is retained within the body of the rivet after installation.(Figure: 4) A 1/8 inch nominal size CherryMAX® aluminum rivet has a single sheer strength of around 664 pounds and a 1/8 inch oversized aluminum rivet with a single sheer strength of around 814 pounds.

(Figure: 5) The CherryMAX® Rivet is inserted into the hole. The pulling head (installation tool) is slipped over the rivet's stem. The installation tool is then actuated. The pulling head holds the rivet sleeve in place as it begins to pull the rivet stem into the rivet sleeve. This pulling action causes the stem shear ring to upset the rivet sleeve and form the "bulbed" blind head. The continued pulling action of the installation tool causes the stem shear ring to shear from the main body of the stem as the stem continues to move thru the rivet sleeve. The locking collar then contacts the driving anvil. As the stem continues to be pulled by the installation tool, the locking collar deforms into the rivet sleeve head recess. The locking collar fills the rivet sleeve head recess, locking the stem and rivet sleeve together. Continued pulling by the installation tool causes the stem to fracture at the break notch. The final product is a blind rivet installation that exceeds the structural requirements of a solid rivet installation. The CherryMAX® rivet has been used on countless airplanes for decades and is considered the only acceptable replacement for a solid rivet. They are 10 to 20 times the cost of a typical pop rivet. However, if you don't have access to the backside of a structure replacing a solid rivet with a CherryMAX® rivet is relatively cheap in comparison to disassembling the aircraft to achieve access for a bucking bar. The key to successful installation of a CherryMAX® rivet is proper hole preparation and rivet selection. Unlike a traditional pop rivet where you continue to pull the rivet until the sheet-metal is sucked together tightly. The precision machined stem and locking collar are designed to function correctly with a very specific and limited material thickness. There is a different rivet length required for every 1/16 (.0625) inch change in material thickness. Improper selection of rivet length will result in improper engagement of the locking collar, or improperly formed bulb on the end of the rivet. This can be a bit of a problem because, after all, the rivet is blind. This is where it becomes essential to use a grip gauge (Figure: 6). Simply insert the end through the rivet hole and hook the lip on the inside of the material. Then slide the depth gauge down flush with the surface of the sheet metal, remove the grip gauge and read the required grip length. If you have not used the CherryMAX® rivet system before, it is essential that you download the CherryMAX® rivet manual from their website. The manual contains essential information and great tips for installation as well as removal of the rivets. There are so many great applications and instances in which we utilize the CherryMAX® rivet, it's hard to imagine how we would accomplish any repair without them. Scan the QR code to download the CherryMAX® rivet manual.

Students are often intimidated when they begin their first fiberglass repair. And rightfully so, if it is their first time working with all of the different materials that fall into the category of "composites". The good news is, that it's not particularly difficult, and with a bit of theory and practice, you will be surprised at the quality of repair that you can accomplish on your own aircraft. In our maintenance classes, once the students have finished their repair projects, we use the "16-ounce ball peen hammer test" on each of the repairs. Hitting the repaired area of a wingtip or wheel fairing with a hammer hard enough to knock it halfway across the shop floor is an excellent way to identify imperfections, but it is an even better way to instill confidence in a student's ability to conduct a proper repair. The vast majority of repaired components show no signs of damage even after this shocking display of abuse. Now, obviously you're not going to test your repairs in the same fashion that we do in the classroom environment, but there are some things that you can do to inspect the quality of your repairs.

Figure: 1 *Brian's 1st composite aircraft project, a Glasair 2S-FT w/ Lycoming IO-540*

The first is the "coin tap test method." This test method is a staple in the composite inspectors toolbox. This is accomplished by taking a smooth edge coin and tapping the surface of a composite structure. The coin will create a very distinct and resonant frequency associated with the underlying structure. If a void or de-lamination is present you will hear an obvious change in the tone. Stiff, highly dense structures, create a higher frequency, and soft, low density structures, create a lower frequency. A "thud" in the midst of surrounding "tapping" noise is an indication of a problem. This inspection method is not only used for testing the quality of a repaired section, but is particularly useful for testing structures that underlie a painted or finished surface where we have no ability to conduct a visual inspection on the fiberglass component itself.

On areas where we have completed a repair, but not yet applied filler, primer, and

Figure: 2 "Back-lit Inspection Method" shows use of excessive body filler

paint, we have an even better method for inspecting the repair itself. The "backlight inspection method." A fiberglass and epoxy repair is somewhat translucent. By applying a strong light to the backside of a fiberglass repair, we essentially can see through the underlying layers of fiberglass and epoxy, somewhat like an x-ray. Discontinuities, stress concentrations, and even de-laminations can easily be seen using this method as long as the thickness of the repaired area is limited. (Figure: 2) Shows what appears to be an excellent repair when observed without the backlight (left column). But using the backlight (right column) shows that the fiberglass cloth had sagged into damaged area of the repair creating a divot. The use of body filler to hide this anomaly is evident when observed with the backlight. Although the repair in (Figure: 3) has some deficiencies when observed externally, the real problems stand out dramatically when viewed with a backlight. In this case, the inadequate scarfing of the repair area

Figure: 3 Back-lit Inspection showing improper scarfing of repair area.

can be seen as a much lighter color indicating the lack of fiberglass in the repair area and over sanding of the repair on the lower right side.

There is one additional inspection item which we use to validate the structural integrity of our repair, the use of "test coupons." Test coupons are two pieces of cured fiberglass layups that are prepped and glued together using the leftover epoxy mixture used for making the repair. These coupons are left to cure in the same environment as the actual repair, and can be later destruction tested to ensure proper curing and bonding of the epoxy. On small, noncritical, repairs, and in the absence of fiberglass pieces, we will simply glue two popsicle sticks together to validate the curing of the epoxy resin.

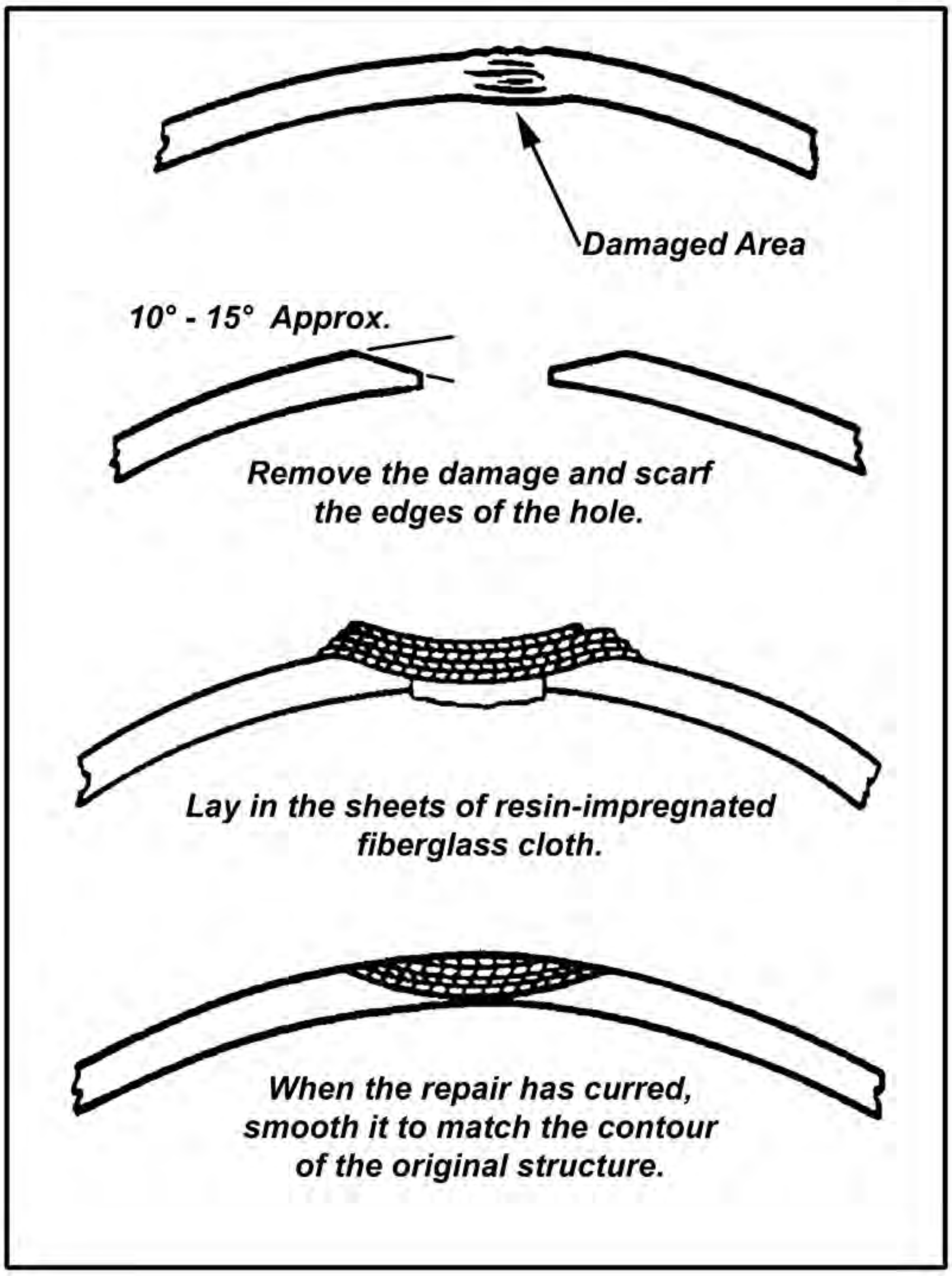

Figure: 4 Fiberglass Scarf Repair

Now that we know how to inspect the repair after it is complete to ensure its structural integrity, we need to look at the procedures for actually completing the repair. The vast majority of work when conducting any repair, involves preparing the surface to apply the layups, and subsequent sanding and finishing after the layups have cured. It is important, before beginning any repair, that you ensure that no grease, oil, or other substances have come into contact with the repair area. The use of soap and water along with a strong detergent may be necessary in order to remove any contaminants. This will require that the repair area be dried extremely well before beginning any repair.

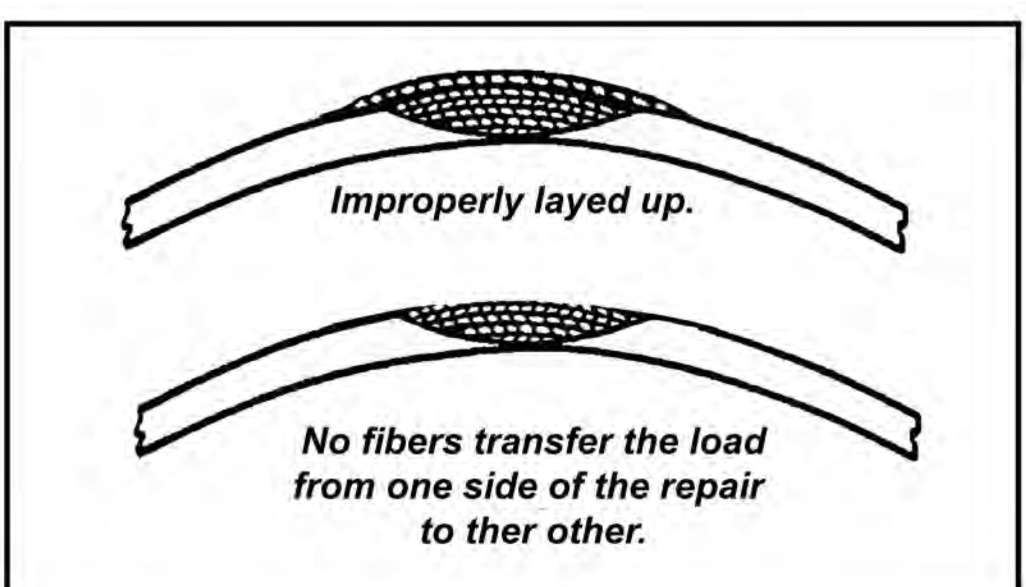

Figure: 5 Improperly layed up repair

The trick to conducting a strong repair, is to scarf the edge of the damaged area as carefully as possible using sandpaper. Thus cre-

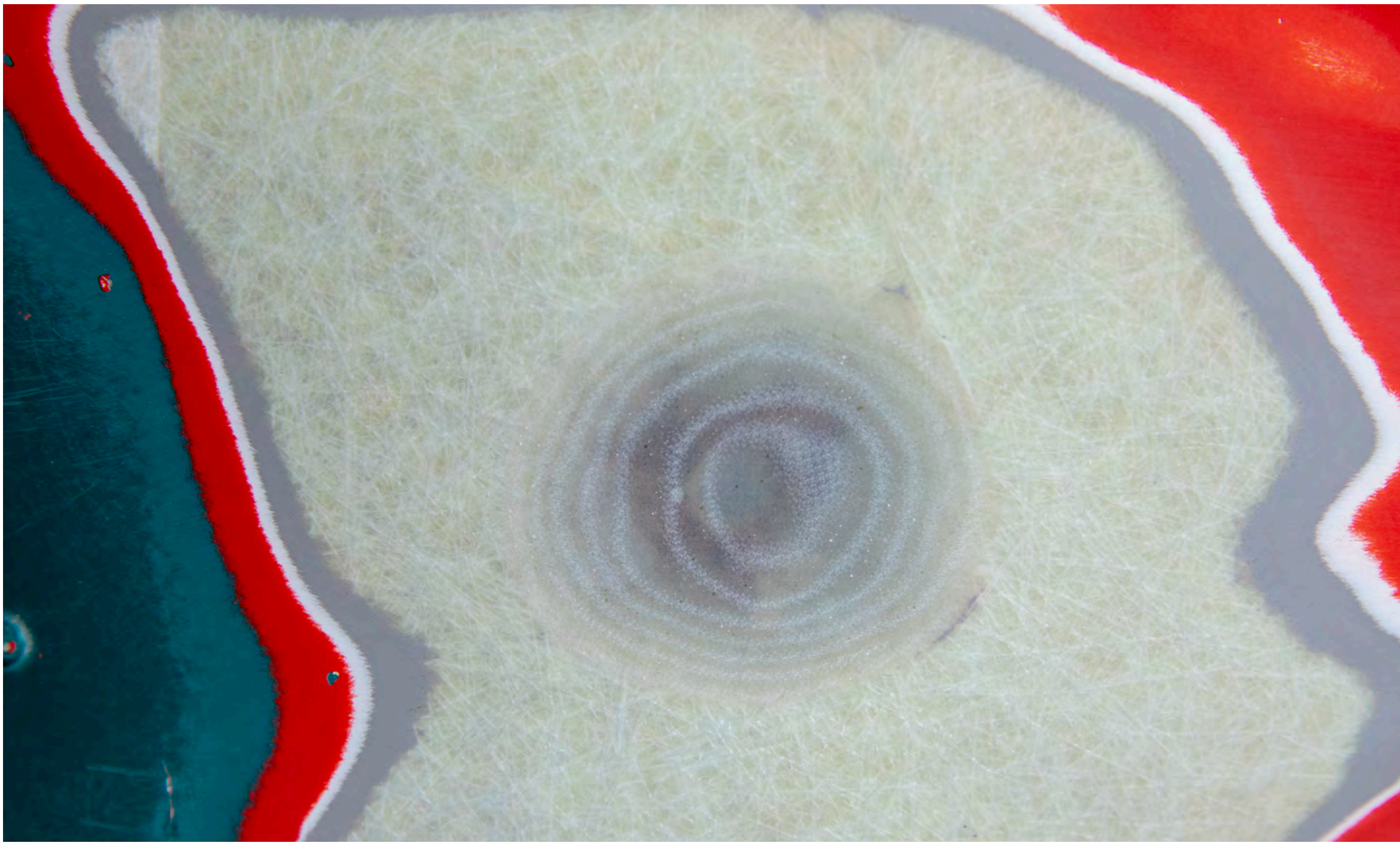

Figure: 6 A Properly Executed Scarf Repair

ating a slope that is paper-thin at the edge of the damaged area, and tapering progressively to the thickness of the surrounding fiberglass.(Figure: 4) This essentially means that if the thickness of the material being repaired was 1/8” thick, the taper should extend outward from the damage approximately 5/8” to 3/4”. This is important because, in a composite repair, the loads imposed on a structure are transferred through the fibers and only through the fibers. The epoxy is simply there to hold the fibers in their proper orientation. If we wish to transfer the load from the repaired area, it is essential that we have a large area for the fibers to attach. Additionally, those fibers need to transfer the load, uninterrupted, through to the other side of the repair. This is the reason that the largest layers of fiberglass cloth are inserted first and progressively get smaller as we reach the surface profile. If we were to insert the individual fiberglass layers in the reverse order, just to say, “fill the hole,” (Figure: 5) we would essentially end up with the fibers trying to attach themselves to the existing structure through a “butt joint”. To make matters worse, when sanding to the final profile, we would be cutting into the fibers on the layers that extend the furthest and carry the greatest load. When properly laid up and sanding to the final profile, the only fibers that get disrupted are at the ends of each piece of fiberglass cloth. Each strand of load carrying fiber is essentially protected by the overlying layers of fiberglass. A properly done repair will end up looking much like the rings of a tree. (Figure: 6) The uniformity in the individual rings of fiberglass can only be achieved by creating an accurate scarf emanating from the damaged area. On these small repairs (normally less than 3 inches in diameter), hand sanding with a sanding block and lots of patients is the order of the day. The better the scarf the stronger the repair. Keep in mind, anytime you are working with composite materials you need to keep from contaminating your work. Blowing the fiberglass dust from your repair with an air nozzle, is of great concern, due to the water and oil contamination from the air compressor. This also means wearing latex or vinyl gloves. Not only to protect your hands, but to protect the fiberglass from the oils that are ever present on your skin. And speaking of sanding, there is a large body of research done to show that the sanding the surface just prior to creating a layup excites the surface on a molecular level improving the bond of the epoxy. And if we are looking to create the optimal strength in our repair, we also need to consider the environment in which we are doing our work. Having the proper temperature and humidity is essential, in addition to having a clean environment.

There is a vast array of different materials and chemicals that are used in different types of composite construction. Whether you are using vinyl ester resin like we used to build the Glasair. Or an epoxy-based system like we used when we were building Lancairs, the processes are very similar. However, each system uses its own particular set of materials and chemicals that are not interchangeable. You shouldn't use a vinyl ester resin to repair an epoxy-based component and vice versa. Do your research. Find out what chemicals and materials are used for the manufacture of the composite parts on your aircraft. Now keep in mind, these types of repairs are typically for what we would call, light load laminate structures. Essentially, nonstructural components like wheel pants, wingtips, and cowling components. If you are new to composite work, these are great places to develop your skills. If you totally screw up, you can always buy a new part. If you think you want to try your hand at composite work, let's give you a couple of additional FAA references to read before beginning your adventure. AC 43.13-1B Chapter 3 Fiberglass and Plastics, and AC 43-214A Repairs and Alterations to Composite and Bonded Aircraft Structures.

Whether you're building a home built aircraft, doing a complete restoration, or just performing routine maintenance, you might like the idea of being able to electroplate your own parts. It may sound intimidating at first, but the process is really quite simple, and it is something that you could add to your inventory of shop tools which you would probably use on a regular basis. It is really rewarding to take an old, ugly looking, rusty part off of your airplane, recondition, plate, and then reinstall the part looking like it is brand-new.

Electroplating is simply the process of depositing positively charged metal particles (ions) displaced from and anode (the material used for plating), moving them through an electrolyte solution with electricity, and attaching them to the negatively charged part which we are going to plate (cathode). The two primary types of plating consist of immersion plating and brush plating. Immersion plating is just as it sounds, is a process of immersing a part into a container of electrolyte solution. Using a power supply, we will provide a positive charge to the anodes submersed around the pe-

Figure: 1 Copy-Cad Plating System

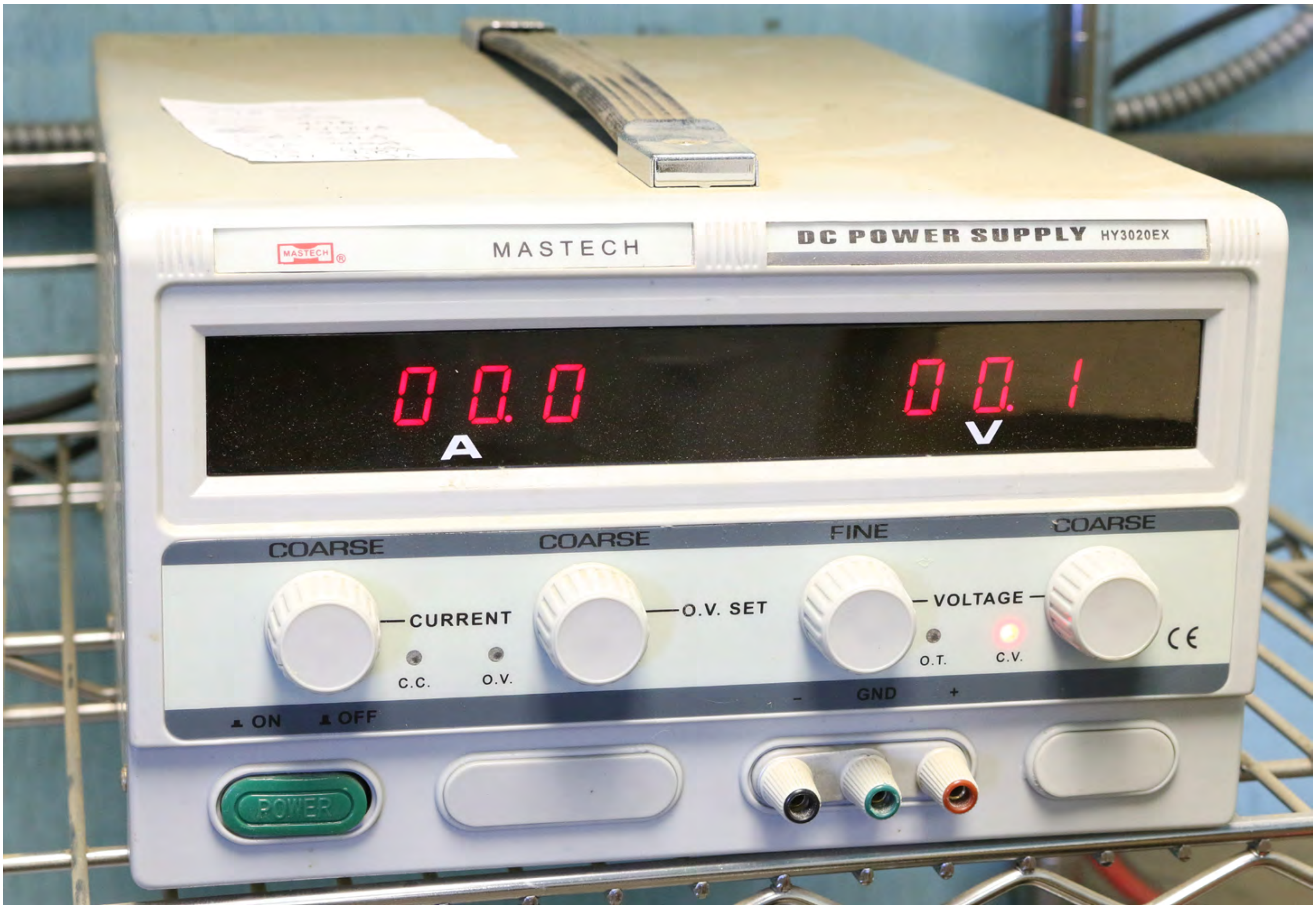

Figure: 2 Constant Current Power Supply

rimeter of our plating container. We will attach the negative terminal of our power supply to the part to be plated. We begin plating by applying current to the system which begins the process of moving the ions from the sacrificial anode to our part. You may even remember this process from junior high science class, plating copper pennies using vinegar as an electrolyte, a zinc coated washer as an anode, and a 9 V battery for our power source.

Brush plating is a miniaturized version of process where we use a small wand or brush wrapped in an adsorbent material (to hold the electrolyte) and connect it to a DC power source. This allows the process to become mobile and even allowing us to plate parts while they're still on the aircraft. There's an entire matrix of different types of base metals that can be plated as well as a variety of plating materials. One of the most common plating processes, that you are probably familiar with in the aircraft industry, is cadmium plating. We always had a desire to set up our shop to do cad plating. However, a little research showed that cadmium is a very toxic substance and the process of plating with cadmium is not very user friendly. We wouldn't recommend this process for the average amateur aircraft builder. This process is probably best left for the professionals with all of the environmental controls in place. We did, however, come across a process called "Copy-Cad." This is much less toxic and has proven to be fairly easy to set up. After a short learning curve, we have our simple set up working efficiently and we use it on a regular basis. Copy-Cad, in reality, is a zinc plating process with a chromate conversion coating applied after plating. This process can generate a coating that looks very similar to Cad and still provides excellent corrosion protection. Since this is our primary plating process that we use in our shop, we fill focus this article around the Copy-Cad system.

Let's take a look at our high-tech Copy-Cad plating system (Figure: 1). The backbone of our plating system is the high quality six-gallon plastic bucket. This bucket has a rubber O-ring on the lid which allows us to close up the system to prevent evaporation of the plating solution. If the solution does evaporate, simply adding more distilled water to the solution will solve the problem. A small 1" x .125" slit is cut into either side of the bucket below the lid where the anode plates can pass through without interfering with the closing of the lid. The anodes are simply .060" zinc plates approximately 6" x 6" with a 1-inch strip cut and bent back to slide through the edge of the bucket. We can use the strips that stick out of the bucket to attach our positive lead to our power supply. Having an anode on either side of the part to be plated will provide for a even distribution of the zinc ion deposits during the plating process. Next we have a 1/4 inch diameter brass rod passing through the entire width of the bucket (and below the lid) that we use for hanging our parts. We will use this rod that sticks out to attach our negative lead of our power supply.

Next we simply need to fill up the bucket with the plating solution. The Copy-Cad solution that we use is a proprietary part A and part B sold by the Caswell company,

Figure: 3 EMG-6 Landing Gear Shock Strut with Copy-Cad and Yellow Chromate

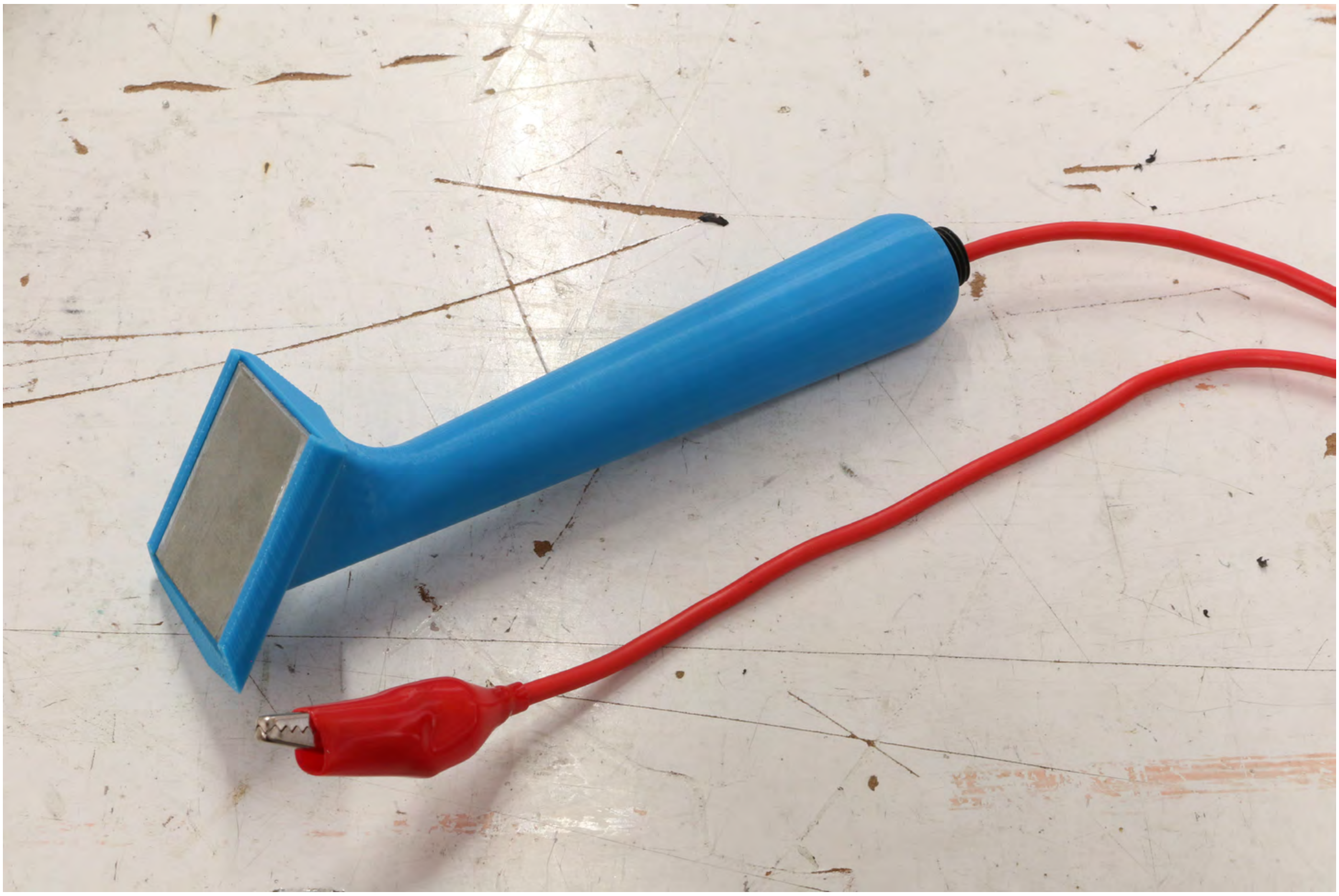

Figure: 4 3D Printed Plating Wand

but is probably nothing more than ammonium chloride and zinc chloride. This all gets mixed in the proper ratios with distilled water to make up the plating solution. We normally will heat the solution to 110° using a simple barrel heater that clips to the edge of the bucket. Next we need to hook up our power supply to the anode and cathode and start plating. Although there are several options for a power supply including even a battery or battery charger, the ideal situation is to have a power supply with the ability to supply a constant current. (Figure: 2). The ideal current works out to a mere .14 amps /sq. in. of surface area of the material being plated. At this current, twenty minutes will result in about .001" plating thickness. The longer that you leave the part, the thicker the plating will be. Although not absolutely uniform in our simple system, we will often use the plating in longer durations to increase the overall dimensions to improve the clearances of certain parts.

You will need to go through a trial and error period in order to develop a feel for the process. Current and timing can really change the final product. The finish can vary from a flat silver almost powdery looking surface to a shiny bright chrome look-alike. The zinc plating is so tough that we can use the wire wheel on our grinder to polish it. We often use a cloth buffing wheel to really make the parts come alive. The parts come out of the Copy-Cad solution looking like chrome or nickel. A secondary process can be applied to the zinc plating called Chromating. We use the yellow chromate which gives that gold iridescent look with ripples of blues and greens mixed in. (Figure: 3) The chromating process, just like conversion coating process of alodine for aluminum, creates an oxide corrosion resistant "crust" that will significantly enhance the long-term corrosion properties of the part. The chromating process takes place immediately after the zinc plating and rinsing. 5 to 10 seconds dip in the chromating solution is usually sufficient to give you the look that you want.

To expand on our plating capabilities we decided to create our own plating brush. About 15 minutes in SOLIDWORKS and we created a 3D model that we thought would work. We 3D printed the body of our design. An additional $8 at the hardware store and we had our own brush plating system. (Figure: 4) The handle is designed to hold a 1.5"×1.5" square piece of zinc that is .060" thick. We wrap the plating end with gauze, dip it in the plating solution, and working with about .5 amps, brush the wand over the part that is connected to the negative electrode. It takes a little time, but is very effective, and after buffing looks just like the parts that have been plated using the immersion process. You can see the obvious difference between the plated side on the right, and the non-plated side on the left. (Figure: 5)

If you've ever painted an airplane, you know the old axiom that 75% of the work is preparation and 25% is primer and paint. The quality and longevity of the paint job really relates the prep work. Plating is no exception. The difference is, that it is probably closer to 95% surface preparation and 5% plating. If you are going to put the prep work into a part for the process of painting is probably easier and faster to plate than

Figure: 5 Plating with the Hand Held Wand paint. If you want the parts to come up shiny, they need to go into the plating solution clean and smooth. A brightener can be added to the solution to improve this process. If you're going for that cad look, plating them right after coming out of the bead blaster works really well.

The Caswell company sells a 180-page manual that covers all types of plating as well as anodizing. If you're going to add plating into your repertoire of capabilities, this manual will expedite the process and shorten the learning curve substantially. With a little bit of Internet research and sourcing, and other supplies that you probably already have, you can set up a small plating system for well under $100. Once you have mastered the process of plating, you will find this to be a really useful tool. Keep in mind, like the old metaphor "if all you own is a hammer, everything looks like a nail," you'll probably find yourself going crazy plating everything you come across.

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Corrosion Prevention (it's money in the bank)

If we had a contest to come up with the maintenance tip that would give you the "biggest bang for your buck" corrosion prevention would easily be in the running for first place. Especially for aluminum aircraft, which will be the primary focus of this article. Corrosion is one of those subjects that isn't very sexy. It's hard to relate to its effects on a short-term basis. But for those of us who have been around for a long time, (old guys) it's easy to see the effects of corrosion and its effect on airplanes over the years. Concurrently, it's also easy to see the effects of corrosion prevention techniques and products. I learned my initial aviation corrosion control training in the US Navy in the 1970s. Conducting maintenance on board an aircraft carrier will really give you an appreciation for the concept of corrosion control. Literally, every aspect of maintenance from structures to electrical required that you think differently in order to combat the effects of that heavy salt water environment on an aircraft. Although the basic principles of corrosion remain the same, the advances in chemical technology has given us an arsenal of new products that have completely changed our approach to corrosion control.

Although the marketing department of any aircraft manufacturer would argue that the purpose of a beautiful paint job is to help sell aircraft. The FAA sees it a bit differently. "The primary objective of any paint system is to protect exposed surfaces against corrosion and other forms of deterioration." This quote comes from AC 43-4A Corrosion Control for Aircraft, a great resource for further information about corrosion and corrosion control.

Figure: 1 Corrosion X For Aircraft

Arguably, properly prepping an aircraft surface, application of an alodine conversion coating, epoxy primer, and a high quality finish coat is one of the most effective methods for preventing corrosion. However, for small aircraft, the concept of painting is a bit of a false flag. There is actually more aluminum on the inside of a small aircraft (that is unpainted) than there is on the outside of the aircraft. This would be the equivalence of painting only the left side of the aircraft. Granted, the painted parts of the aircraft will be protected, however, the life of the aircraft as a whole would not be extended. In our metaphor, the unpainted portion on the right side of the aircraft would eventually become corroded to the point that would render the aircraft unairworthy. Most aircraft fall into this same paradigm but rather than thinking about the problems as right and left side of the aircraft, we are talking about outside and inside of the aircraft. One of the primary reasons for an aircraft being removed from service permanently, is corrosion. It's not uncommon that an individual gets duped into purchasing an airplane that has hidden corrosion internally. Often, the severity of corrosion is only identified at annual inspection or upon disassembly for other repairs. On occasion the corrosion is so severe that it becomes no longer cost-effective to repair. "Out of sight, out of mind" really applies here. One obvious solution is to paint the entire airplane, both inside and outside. On large aircraft, both commercial and military, it's commonplace that each one of the components are individually painted before assembly. This makes for nearly bulletproof corrosion prevention technique.

But like everything, there are several downsides to this process. Even on a small Cessna, the additional cost for this process can add tens of thousands of dollars to the cost of the basic airplane. The cost benefit analysis shows this to be cost-effective only on small aircraft operating on floats, particularly those aircraft operating in a saltwater environment frequently. For the light sport world this additional cost would certainly be a significant factor, however, the more significant downside is the additional weight. When we are limited to only 1320 pounds for a 2 place aircraft, even the weight of paint becomes a significant variable in the design considerations. These practical considerations leave most small aircraft manufacturers as well as aircraft

Figure: 2 ACF-50

builders to choose to paint only the outside of their aircraft. So the question becomes, how do we protect the internal portions of the aircraft. The simplest and most effective method is to apply an anti-corrosion treatment. The two most popular products in the aviation market are currently Corrosion X (Figure: 1) and ACF-50 (Figure: 2). Both of these products are much different than the traditional corrosion preventative compounds that we have used in years past. These products are formulated to be attracted to the metal through a process the manufacturer calls “polar bonding.” The product sticks to the metal like a magnet making it much more difficult to wash away. This polar bonding is also responsible for the products ability to creep and flow evenly over surface leaving a .0002” protective layer. Even on aircraft with existing surface corrosion, the penetrating ability of these compounds will seep into any corrosion cell emulsifying the moisture and sending it to the surface where it can evaporate. Without moisture (electrolyte) the corrosion is virtually halted. In the past, using the standard Mill Spec corrosion preventative compounds, we were able to coat the inside of a surface which did a great job of protecting everything that was visually accessible. But the poor penetrating capability would still

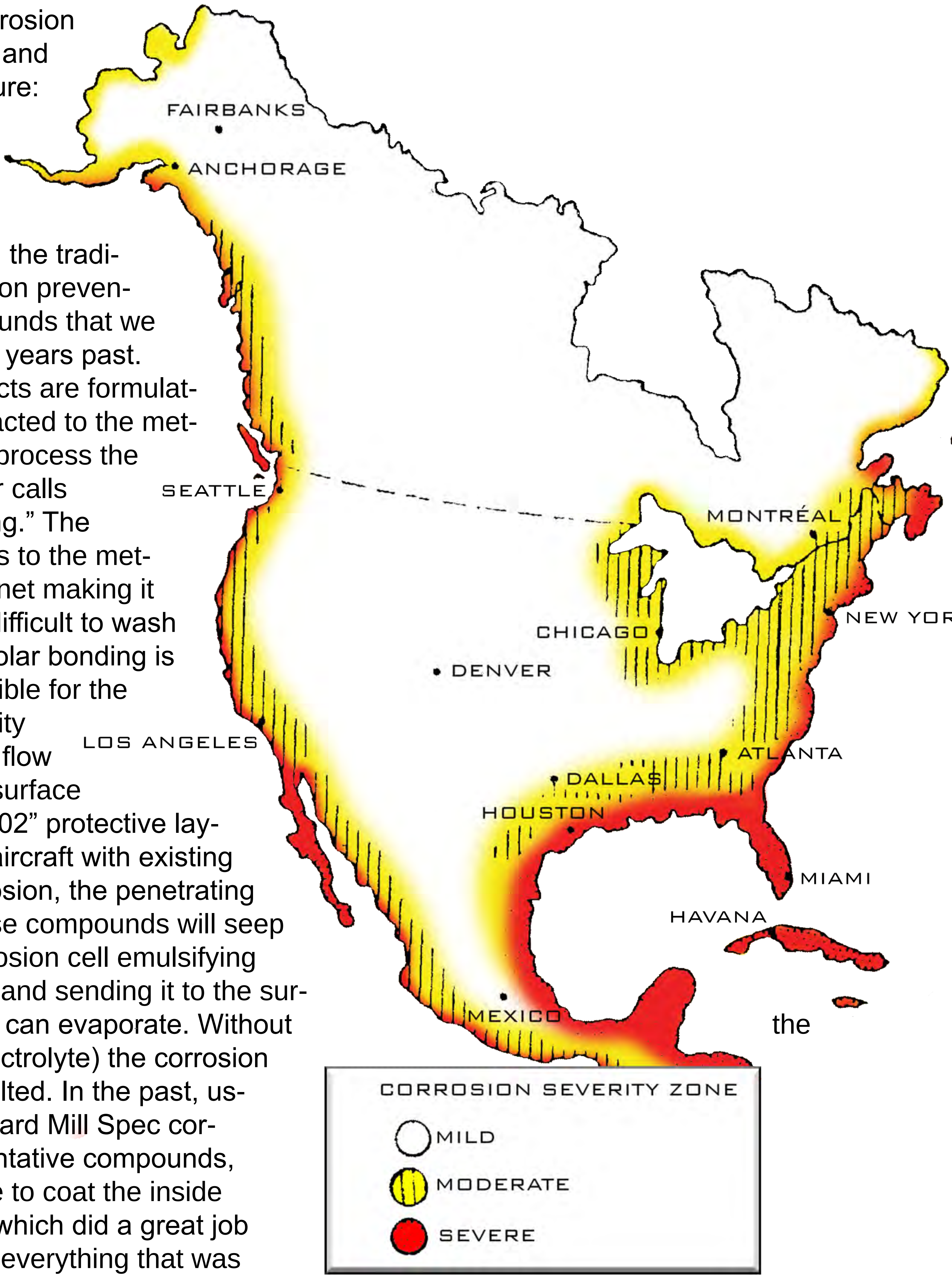

Figure: 3 Corrosion Severity Zone Map

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leave much of the most important structure vulnerable to corrosion. The joints and seams. Water would very easily penetrate in between the seams through capillary action leaving these areas not only vulnerable, but aggressive promoters of corrosion because the enclosed seems would draw in moisture which in turn could not easily evaporate. Screws, bolts, and other fasteners were susceptible to dissimilar metal corrosion for much the same reason. Once the screw has been removed, the paint surface would be broken leaving a pathway for moisture into the surface between the fastener and aluminum. The penetrating properties of both Corrosion X and ACF-50 will creep into every “nook and cranny” or should we say “rivet and bolt”, virtually eliminating the possibility for corrosion in those critical areas that are not normally visible.

A corrosion cell is basically a battery. For corrosion to exist we need the four basic elements of a battery: an anode, cathode, electrolyte and a path of current. Eliminating any one of these four elements can stop the corrosion process. The added advantage of these new anti-corrosion products are there dielectric properties. Not only do they displaces the electrolyte, they leave an ultra-thin dielectric film that blocks the path of current. With dielectric properties in excess of 39,000 volts these products are particularly useful when it comes to wiring, electrical components and electronics. We use these products on electronic components much more aggressively than we are willing to admit in this article. But even just using it on connectors and ground connections has probably reduced our avionics and electrical component failures by half. Some of the other areas where we find these products to be particularly useful are engine compartments, battery box, battery terminals, control cables, control hinges, and just about anything that needs lubrication.

So far, we have been talking about why and where to use these corrosion treatments on your aircraft. To complete the discussion we need to talk about when to use the products. On the corrosion severity zone map, (Figure: 3) enhanced from the FAA’s advisory circular AC 43-4A, we can see the typical conditions and locations that are more conducive to a corrosive environment. Humid, hot, coastal environments typically lead to a highly corrosive conditions. While dry, cold environments are more ideal. Airplanes that live in the coastal regions typically will show signs of corrosion within a couple of years, while an airplane living in, for example, Arizona may showed little to no signs of corrosion even after 20 to 30 years. If you have an aluminum airplane, we recommend an anti-corrosion treatment under all circumstances. The absolute best way to deal with corrosion is not to let it get started in the first place. There are many locations around the country that are so dry that a treatment once every 10 years would be adequate. On the other hand, the majority of population centers and, as a result, airplanes are located in the moderate to severe zones. In these areas, the frequency of corrosion treatment will need to be kicked up a notch. There are many areas where it would be cost-effective to be doing a corrosion treatment on a yearly basis. When looking to purchase an aircraft (like real estate) it is “location, location, location.” The one mitigating factor is seeing consistent corrosion treatments in logbook entries. Finding an aircraft that has been treated early in its life and seeing no visible signs of corrosion externally will give you great confidence that the structure which is hidden from view will be sound as well. Waiting to do your corrosion treatment until after the aircraft has seen significant signs of corrosion is kind of like closing the proverbial barn door after the horse has left the barn. It’s not often that we find such an easy, simple, and cost-effective way to protect our aircraft. Think about investing in your aircraft.

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Yes it's true, the topic of pre-ignition and detonation has been previously written about in grueling detail. However, almost every article published on the subject broaches the topic with the assumption that we are all flying either a Continental or Lycoming powered aircraft. In this new era of the light sport aircraft is time to revisit the topic with a slightly different slant. And in particular, because the majority of the aircraft in the light sport an ultralight aircraft categories are powered by Rotax engines, we will skew the topic towards the Rotax two and four stroke engines. There are two significant differences that generate the necessity for this new discussion. First of all, the Rotax engines do not employ an in-flight adjustable mixture control. And secondly, by regulation, the light sport aircraft are not allowed to incorporate an in-flight adjustable propeller. Both of these items can have a significant impact on the topic at hand.

To begin with, we need to start off with some basic theory on what takes place inside the combustion chamber of a typical cylinder during the combustion process. And because we are interested in theory primarily, we will stay away from very specific numbers so that we may span a very large cross-section of different engines. Normal engine combustion begins with a spark across the electrodes of the spark plug igniting the fuel/air mixture and forming a small "kernel" of flame. This flame front grows outward from this original kernel propagating across the combustion chamber. Ideally, the flame front surface area grows out smoothly, but at an exponential rate increasing the amount of pressure within the combustion chamber until all the fuel is consumed. By precisely timing the beginning of the spark event at a specific distance before top dead center, we can control the location (crank angle) where the engine develops its peak pressure. And as a result, provide a nice smooth push on the piston throughout the power stroke optimizing the conversion of cylinder pressure into crankshaft torque. (Figure: 1) Shows a typical pressure distribution within the com-

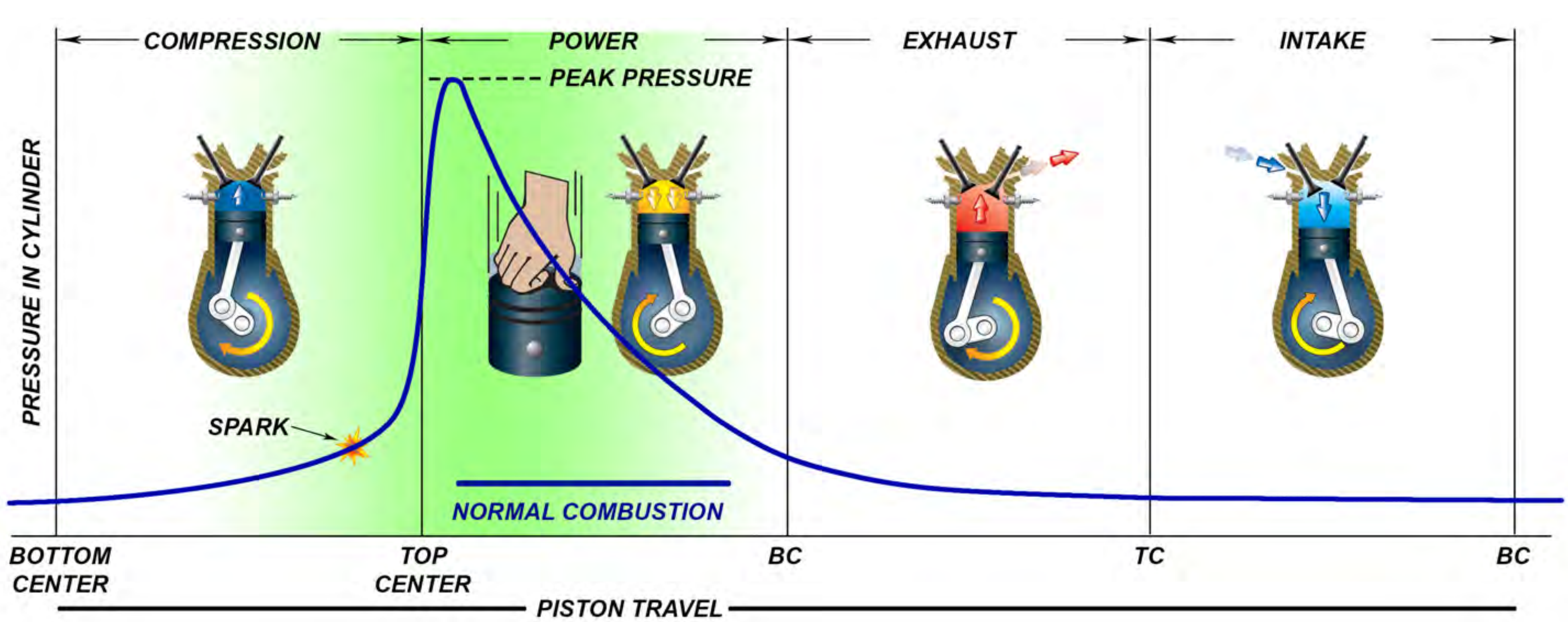


Figure: 1 Cylinder Pressure (Normal Combustion)

bustion chamber of a normal four cycle engine. For this discussion we are primarily interested in the area from compression through the power stroke offset in green. By focusing solely on this segment, we can also include the two-stroke engine in the discussion.

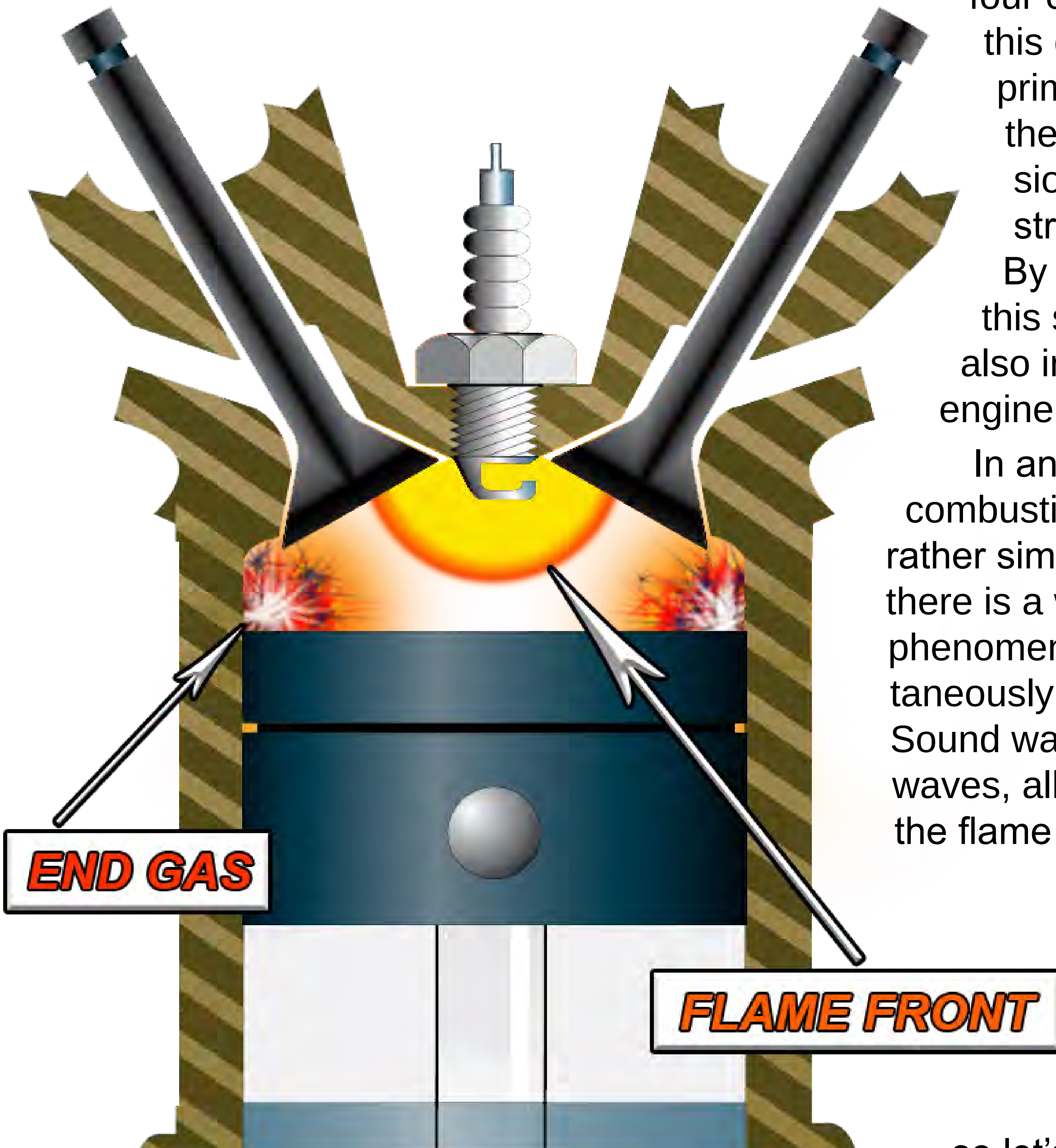


Figure: 2 End Gas Auto-ignition

In an ideal world this combustion cycle would be rather simple. But in reality there is a whole host of other phenomenon occurring simultaneously during this process. Sound waves and infrared light waves, all traveling faster than the flame front can have a significant impact on the combustion process. (This is where it's really easy to get off into the weeds, so let's keep it simple.) As the flame front propagates from its original point of ignition, the pressures build throughout the entire combustion chamber. Affecting not only the pressure and temperature at the flame front, but also at the unburned fuel not yet reached by the flame front. These are typically referred to as "end gases". If the temperatures and pressures reach a critical point, these "end gases" can auto-ignite. (Figure: 2) Unlike the relatively slow burn of the flame front, these spontaneously combusting pockets of end gases could be visualized as localized "explosions" for the lack of a better description. If auto-ignition of the end gases occurs, we can see a dramatic increase in pressure within the cylinder from a combination both the normal flame front and the unwanted end gas "explosions". These end gas explosions in turn create greater temperatures and pressures propagating more end gas combustion resulting in a sawtooth pattern of pressure oscillations. (Figure: 3) In a car you may be familiar with this phenomenon commonly identified as "knocking" or "pinging". These end gas explosions are by definition "detonation". Rather than providing the normal smooth push on the piston of a normal combustion cycle, with detonation, the majority of the energy is converted to heat and pressure at or near top dead center and long before the piston, connecting rod, and crankshaft are in a position to convert that pressure into torque. Contrary to the analogy of the smooth push on the piston, what we would end up with is a sudden and sharp impact. The fuel air mixture still provides the same amount of potential energy or BTUs (British thermal units), however, in the case of detonation, that force gets directed into engine components over a very short time interval in the form of extremely high temperatures and pressures leading to damage or destruction of the engine.

So far we've been talking about detonation in the extreme. But in reality, detonation can occur at many different levels. Now that we understand that detonation is simply the spontaneous combustion of the end gases, you can visualize a case where the normal flame front has consumed all but the very last remnants of end gases before auto-ignition begins. In this case, the amount of fuel air mixture remaining to auto-ignite is so small that the amount of detonation would raise the temperatures and pressures only slightly.

All fuels are subject to detonation. All that is required is to raise the temperature to the point of auto-ignition. Different fuels have different auto-ignition points. And in particular, gasoline has different auto-ignition temperatures primarily controlled by the octane rating of the fuel. The higher the octane rating, the higher temperature necessary to cause auto-ignition. And since pressure is directly related to temperature, having a higher compression ratio engine will drive the com-

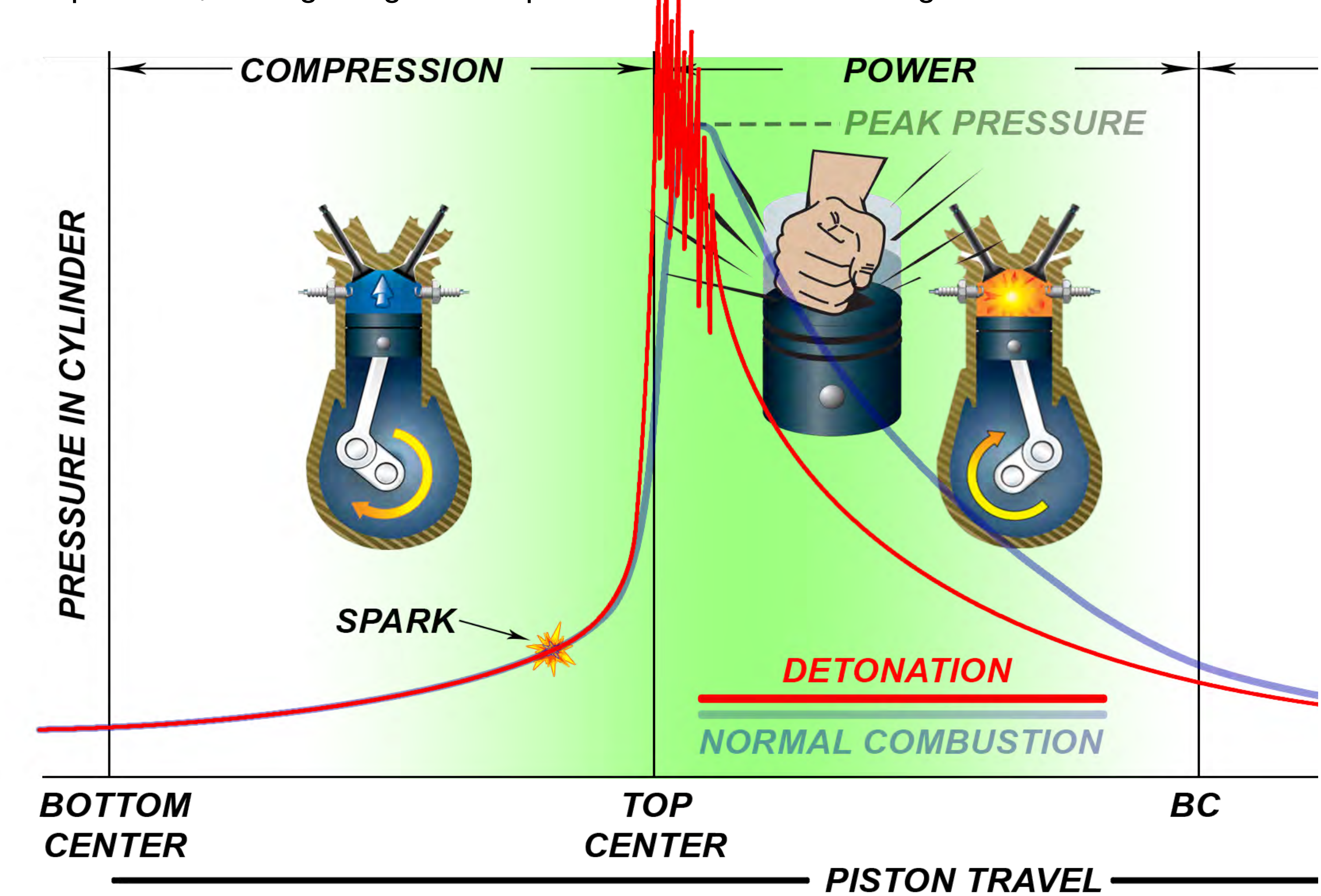


Figure: 3 Detonation

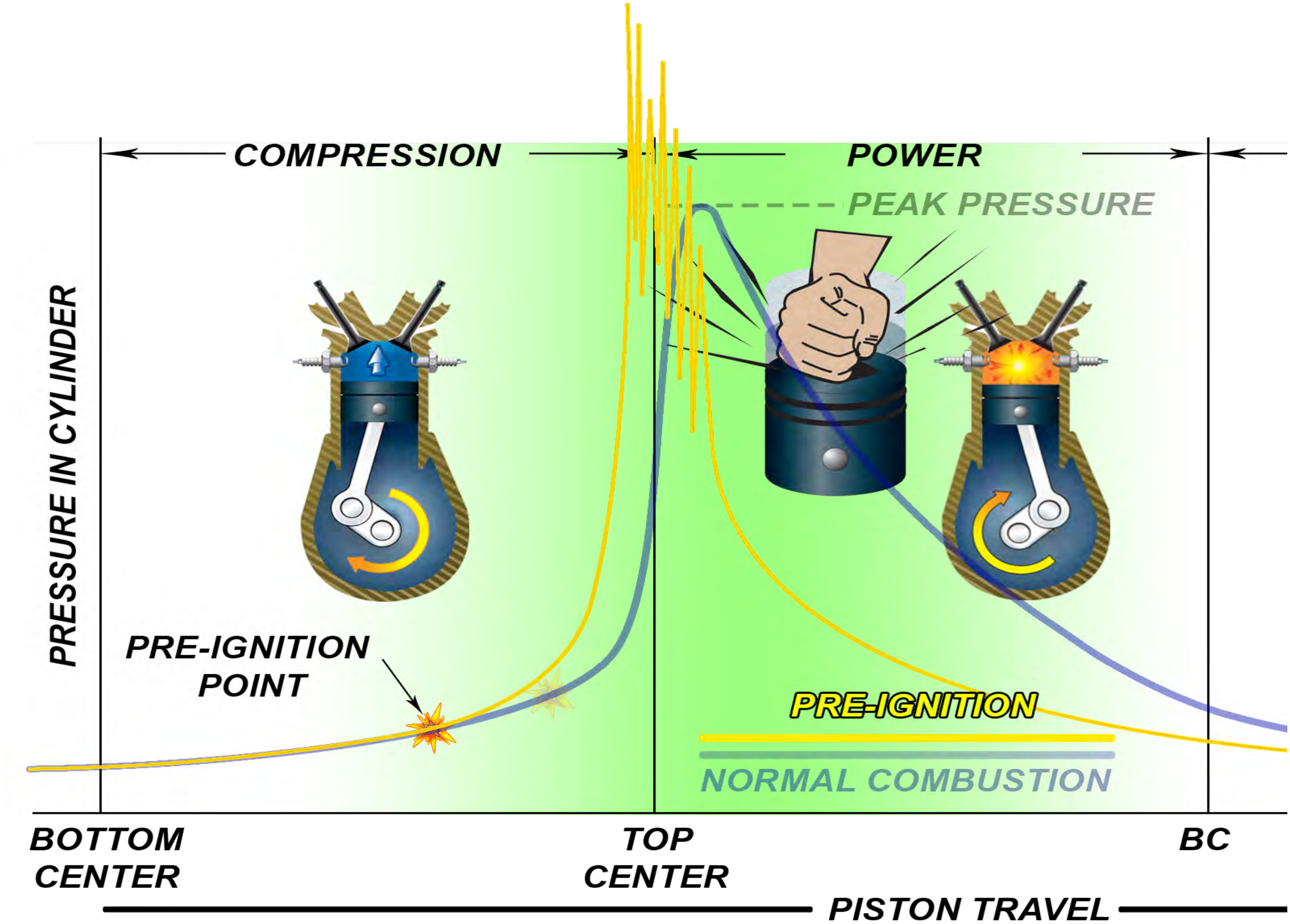


Figure: 4 Pre-Ignition

bustion chamber temperatures higher. This is the reason that a Rotax 912UL (80 hp) with a compression ratio 9.0:1 can use "regular" 90 RON (research octane number) gasoline, while the Rotax 912ULS (100 hp) with a compression ratio of 10.8:1 is required to use "premium" 95 RON gasoline, or 91 AKI (Antiknock index) as you would buy it at the pump. And if compression ratio is that significant you can get an idea for the necessity for high-octane aviation fuels when we start using engines with turbochargers or superchargers. By "jamming" more fuel and air into the engine we can get more horsepower. However, with these increased pressures and as a result, temperatures, comes the necessity for higher octane aviation fuels. Many different chemical compounds have been tested, and used over the years, trying to find the best solution for suppressing detonation. Tetra ethyl lead soon won the day and became the standard compound used in both aviation and automotive fuel to suppress detonation. Tetra ethyl lead is still used today in aviation fuel. But by the 1970s the petroleum industry started the process of eliminating the tetra ethyl lead in automotive fuel due to environmental concerns and gas companies now control detonation properties with the whole host of other chemical compounds.

We have identified normal combustion and detonation, but we have yet to discuss pre-ignition. (Figure: 4) Pre-ignition is often used in casual conversation in place of or in conjunction with detonation. And, although, there is a significant overlap, let's put some definitions on the table. By definition, pre-ignition is a situation in which the fuel-air mixture in a spark ignition engine ignites before the timed spark. Typically, because of contact with a hot surface. This is different than detonation in that detonation is the spontaneous combustion of the end gases. However, with pre-ignition, once the fuel has been ignited, it will propagate a flame front similar to that under the normal combustion process. The problem, however, is this flame front propagation is occurring well before top dead center causing a dramatic rise in cylinder pressures which inevitably lead to detonation. And because these pressure increases occur even closer to top dead center than with detonation, pre-ignition has the potential to do even greater damage to the engine. Also, detonation, even light to moderate detonation increases cylinder and piston temperatures creating the potential for a hot spot which will once again lead to pre-ignition, which in turn leads to more detonation, and so on. So you can see the tendency for the two terms to become intermingled.

We have now laid the foundation which will give us the ability to discuss in more practical terms some of the concepts, problems, and solutions surrounding detonation and pre-ignition in light sport and ultralight engines. We have just begun to scratch the surface of this topic. And In our next article, we will take an even deeper dive into the nuances of detonation providing you some tools for inspecting, troubleshooting, and avoiding detonation and pre-ignition on your aircraft.

In part one of this article we discussed the foundation and theory of detonation and pre-ignition. In this article we want to expand upon that foundation and look further into the real world results of pre-ignition and detonation. To recap, pre-ignition is a situation in which the fuel-air mixture in a spark ignition engine ignites before the timed spark. Detonation is simply the spontaneous combustion of end gases ignited by reaching their critical temperature prior to being reached by the normal flame front.

The method by which we prevent detonation, under normal circumstances, is by providing a high enough octane fuel to prevent spontaneous ignition of the end gases before the normal flame front reaches them. The higher the octane, the greater temperature necessary for spontaneous combustion.

One of the more important factors, when looking at engine operation, is to look at the normal combustion pressure curve on our diagram (Figure: 1). There is a given distance from the spark (point of ignition) until TDC (top dead center) and for that matter, any other point within the power stroke. This also means that at a given RPM and throttle setting there is also a specific time interval from the point of ignition until TDC. The amount of fuel that is burned from the point of ignition until top dead center can be directly related to this time interval. The longer the time interval the more time available for fuel to combust. This means more pressure, and more temperature, within the combustion chamber both before and at TDC.

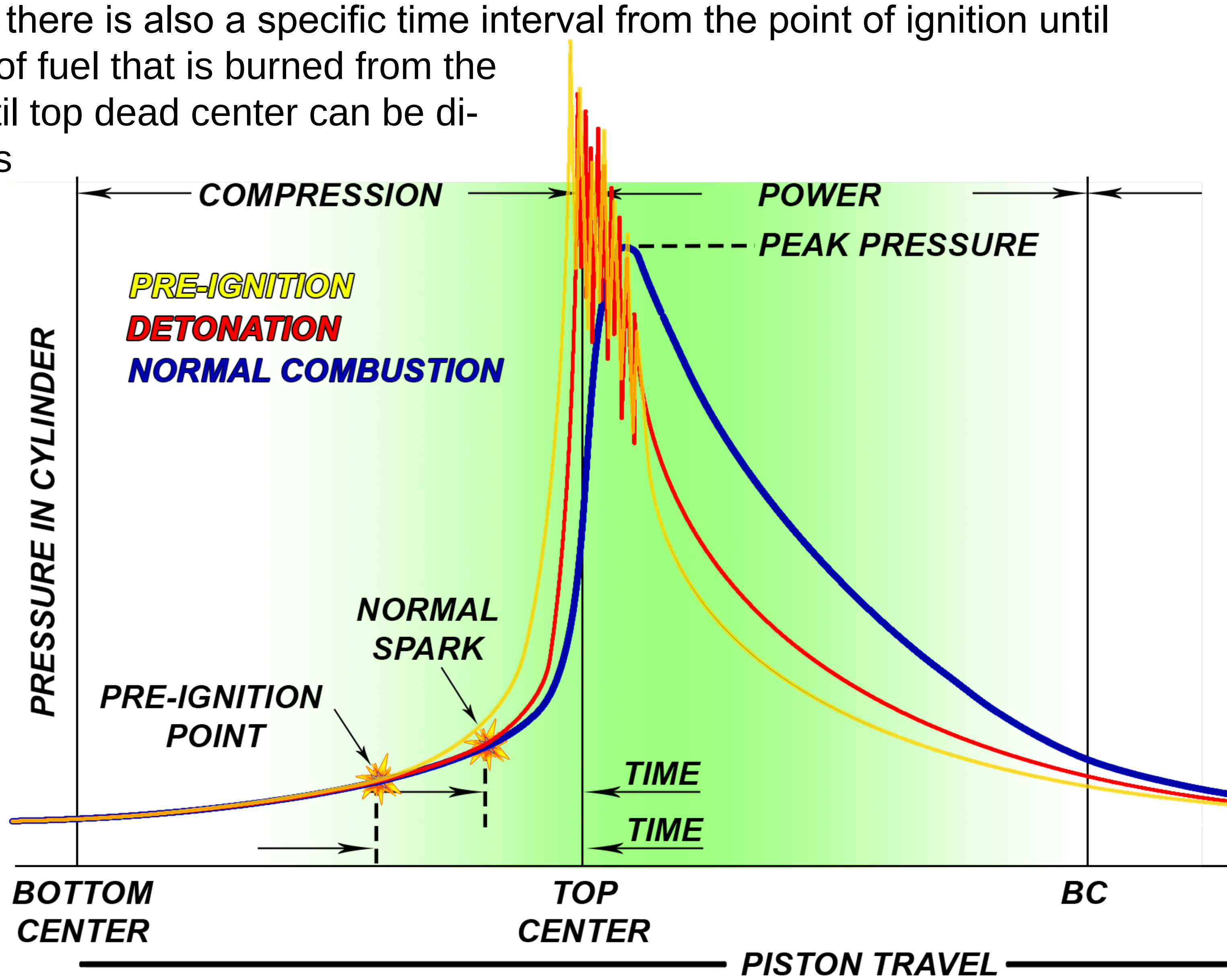


Figure: 1 Cylinder Pressure

If we want to relate this to pre-ignition, or even improper-

Figure: 2 Rotax 582 Piston with Pre-ignition and Detonation

ly timed magnetos, you can get an even more dramatic indication of what will happen inside of the combustion chamber. (Figure: 2) In its extreme, pre-ignition, allows a significant amount of the fuel to be burned before we reach top dead center. This can easily raise the temperatures and pressures within the combustion chamber to the point of self ignition and detonation. The “cutting torch” effect at the ring end gap, and the “shock wave” disruption of the carbon deposits in the same area are the results of detonation. These end gas pockets of spontaneous combustion are the result of temperatures and pressures within the combustion chamber reaching critical temperature. However, the primary cause of the pressure and temperature increase is a result of the fuel being ignited long before the normal spark. The greater the amount of fuel which is burned before top dead center, means the greater the temperature and pressure and consequently, less fuel and energy available after top dead center to be directed into the crankshaft to produce power. This loss of power can be catastrophic to the outcome of the flight. Even with the best of circumstances, a dead stick landing with a successful outcome still leaves you with an engine suffering substantial internal damage.

In this example (Figure: 2) of pre-ignition is on a Rotax 582 piston from a Quicksilver GT-500, a complete forensic analysis found the cause of the accident to be related to a minor, but persistent leak in one of the hoses attached to the water pump. On the third takeoff of a three leg cross-country flight, the aircraft suffered engine stoppage shortly after departure. It was found that the water in the radiator and engine had dropped to a sufficient point, no longer providing cooling for the cylinders and head. As the cylinder heads heated up, the spark plugs were no longer able to dissipate the heat and created a hot-spot on the spark plug. This allowed the fuel air

Figure: 3 *Spark Plug Pre-ignition and Detonation*

mixture to ignite before the normal ignition source causing the classic pre-ignition and subsequent detonation. We know that the temperatures and pressures that occur during pre-ignition and detonation are extremely high. (Figure: 3) Shows melting of the spark plug metal electrodes. These electrode deposits can be seen on the perimeter of the spark plug as well as the top of the piston. In addition, the temperatures were high enough on the ceramic insulator to create indications which look like bubbles of melted glass.

Let's be clear, the pre-ignition is what is allowing the pressures and temperatures to increase to the point of spontaneous combustion (detonation) of the fuel air mixture. However, it is the detonation that is doing all of the damage. Pre-ignition almost always leads to detonation and detonation has the possibility of heating spark plugs or carbon deposits to the point of creating pre-ignition. Identifying the cause of the damage, or failure, is usually what allows us to be able to identify whether or not pre-ignition was the instigator.

Detonation by itself, without the component of pre-ignition, requires that the pressures and temperatures within the combustion chamber to become critical by some other means than igniting the fuel too early. Interestingly enough, there is another element that is similar to pre-ignition. When we overload an engine, let's say, for example, by adding too much pitch into the propeller, what we are essentially doing is slowing down the time interval from the ignition point until top dead center. This essentially allows more fuel to be burnt over a smaller distance of crankshaft travel. This, in turn, increases the pressures and temperatures within the combustion

Figure: 4 *3 Levels of Detonation*

chamber. If the pressures and temperatures become critical simultaneously with the normal flame front reaching the last remnants of unburned fuel/air, there may be no adverse effects on the engine whatsoever. However, if the pressures and temperatures become critical prior to normal flame front reaching the end gases, there will be detonation. (Figure: 4) shows three examples of Rotax 582 pistons exposed to different levels of detonation. On the far left we see the dome of the piston in its original configuration as, an example, without any detonation. In the center, we see a piston with a “dent” caused by detonation. On the right, we see a piston with an even greater degree of detonation and extreme deformity of the piston dome. Ironically, the two pistons with denting never failed. The operators of the aircraft were unaware of this condition, and the problem was only identified by a thorough visual inspection by a judicious LSRM while conducting a 100 hour inspection. Investigation revealed that these pistons may have been operating with varying levels of detonation for quite some time. The detonation pattern can be seen by the disruption of the carbon deposits on the top of the head emanating from the “squish zone” around the perimeter of the piston. Although, this is what we would refer to as “light” detonation, the timeframe of exposure created the scenario where the repeated “hammering” of detonation slowly deformed the metal. The root cause of this detonation was related to an overloading of the engine from a oversized propeller with too much pitch. And unlike our Continental and Lycoming powered brethren, we don’t have the option for in-flight adjustable propellers. As a result most of the light aircraft use a ground adjustable propeller. This allows pilots to unintentionally adjust propellers outside of the normal operating limitations of the engine. The most common complication, comes from someone trying to get that extra 2 mph out of their aircraft in cruise. This essentially increases manifold pressure, and cylinder head temperature. If overdone and especially when combined with a few other anomalies, we can easily push the cylinders into the realm of detonation. We have seen this scenario of denting the cylinder head in the past, but never to this extreme without failure. It just goes to show you the robust nature of the Rotax 582. Both of these pistons were from the same engine. The most common question we get regarding these two pistons is “why the differential in denting?” Always a great question, and these are excellent training aids as they shows the importance of carburetor synchronization. If you open up one carburetor greater than the other, you increase the load on one cylinder and decrease the load on the other cylinder. We often see single cylinder failure from detonation that will point to carburetor synchronization as at least a contributing culprit.

Figure: 5   3 Catastrophic Detonation

So the unifying theme has been, the fuel air mixture reaching a critical pressure and temperature that results in detonation. And although, we are just scratching the surface when it comes to causes, it wouldn't be right to leave the subject without talking about a more obvious reason. You probably have been thinking that mixture has got to be a significant factor when it comes to detonation. And, of course, you're right. This is particularly important, primarily because unlike most Continental and Lycoming powered aircraft, in the Light Sport world we use the Bing carburetors. These carburetors do not have the ability to control the mixture in-flight. Of course, having control over the mixture is a (metaphorical) double-edged sword. If you know how to use it properly, it can be a very effective weapon. In the hands of a novice, you're likely to end up stabbing yourself. The downside to not having a mixture control is not being able to mitigate a situation rapidly heading south. We rely on the aircraft being set up properly, and the maintenance being done correctly, before we ever fire up for our hundred $100 hamburger. The good news is, once we have the engine/carburetor set up correctly, the reliability of these engines are very high. And because there is no mixture control, it's hard for the pilot to screw things up once in the air. This is probably a good thing. On the two-stroke engines, the time interval, once pre-ignition or heavy detonation has begun until total engine shut down, is just seconds. Figure: 5 shows an example of heavy detonation as a result of excessively lean mixture. The total time frame from first indication until engine seizure was less than 5 seconds. Not much time to mitigate any failure. With years of training and knowing what to listen for, we have been able to identify detonation in flight before failure. However, it is normally considered impossible to hear detonation occurring in an aircraft because of the high noise level. As a result, it is possible to suffer mild detonation and not be aware. Training an individual to heard this is nearly impossible, after all, each training interval would last only 5 seconds and cost you a new engine. Let's just say, the best way to eliminate pre-ignition and detonation is to have your aircraft set up, operated, and maintained properly.

Now that we have looked at both the theory and some of the practical aspects of detonation, you should be able to incorporate this knowledge into your next inspection. We strongly recommend incorporating a simple bore-scope inspection of the cylinders at each inspection cycle. Once you learn how to "read" the combustion chamber, you can start to make some much more enlightened decisions about the health of your engine.

Having built and flown model aircraft back in the 1960s, we have a fairly decent historical perspective on model aircraft power systems. Watching the transformation in the model industry, from gasoline to electric, got me to thinking. In just a few short years, the model aircraft industry completely evolved and morphed into a sport dominated by electric motors and batteries. Initially, the transformation was simply replacing the gas powered models with electric motors. But the innovation throughout the industry soon overwhelmed convention. The ability for distributive power, thrust vectoring, reverse thrust, and a whole host of other innovations soon proliferated the market with practical flying machines which only a decade ago were things of science fiction. So what was it, in the model aircraft industry, that converted gas powered motors to collectors items at such a dizzying pace? And, if that could happen, what would prevent this from happening across all of aviation?

One of trends in the model aircraft industry was that the initial utilization of electric motors were on the very smallest of aircraft. As battery and motor technology improved, we saw increasingly larger electric motors appear on the scene. It wasn't long and we started to see 16 kW (21.5~ hp) electric motors powering giant scale RC aircraft producing nearly 100 pounds of static thrust proliferate the industry. One of Brian's first ultralights was a Quicksilver model E powered by a 15 hp Yamaha motor turning at 15,000 RPM. We thought if we could fly that Quicksilver with a 15 hp engine, why wouldn't a model aircraft electric motor work just as well? This was going to require some additional investigation. We intuitively understood that the batteries were going to be the primary stumbling block. This necessitated a further analysis of the battery issue with regards to weight versus energy density in comparison to a gasoline powered engine. The calculators came out and we got to work. We searched the Internet up and down, left and right. Even 10 years ago, we found a fairly wide variety of power plant and battery systems with potential. This broad-spectrum analysis laid the foundation for a layman's description that we use on a regular basis which describes the realities of electric power in aviation today.

> ***"So what was it, in the model aircraft industry, that converted gas powered motors to collectors items at such a dizzying pace? And, if that could happen, what would prevent this from happening across all of aviation?"***

For a baseline let's use a Rotax 447, one of the most popular ultralight engines: 40 hp and 34 ft-lb of torque. With a B gearbox and electric starter the total weight is 93 lbs. Compare that to a 40 hp electric motor, say, the German built Nova 30 (Figure: 1). With nearly 60 ft-lbs of torque this motor weighs in at a mere 14 pounds. Add a controller and we are at 20 pounds. This leaves us 73 pounds of batteries added to the equation before we get to the zero fuel weight of the two-stroke Rotax. Granted, based on the installation there may be several other additions necessary to be able to fly both configurations. But for the sake of making our point, we have simplified the analogy. In this configuration, without any gasoline in the 2 stroke configuration, the weight is the same, however, we can fly the electric configuration until we use the energy stored in the 73 pounds of batteries. Whereas in the two-stroke configuration, we are grounded until we add gasoline. When we start adding gasoline, and a few more batteries, we eventually end up with a configuration in equilibrium, where the weight of the power plant installations and the flight times are comparable. Our calculations show that utilizing off-the-shelf, low cost, lithium polymer batteries from the model aircraft industry, will garner us a 23 minute flight time. Less than 23 minutes favors electric power. More than 23 minutes exponentially favors gasoline power.

This made perfect sense. In the model aircraft industry the necessity to fly great distances is nonexistent. The primary mission involves getting into the air, having fun, flying for 10 to 15 minutes, and landing. When you want to fly again, simply replace the battery and start the process all over again. The shorter the flight time, the lower the weight, and the greater the performance. In the human caring side of aviation, this seems extremely impractical. The most common mission is, well, we want to go someplace. While others within the electric aircraft industry currently tout numbers of 45 to 60 minutes as the break-even point, this still doesn't bridge the mission gap. The primary reason for this increase in break-even flight time is simply, battery energy density. Even 15 years ago the break-even point would've been only 12 to 15 minutes. Historically, we now have a lot of data showing that the battery energy density (Wh/kg) has been, and continues to increase the rate of about 5% to 8% per year. Although, the growth rate in individual battery chemistries increase at a much slower and linear rate, the improvements in overall battery energy density is primarily a result of the innovative new chemistries being brought to market every year. If this trend continues, that would suggest energy densities equivalent to gasoline within 50 years. There are many skeptics about this possibility. But let's back up and look at the bigger picture. Most electric motors in aircraft today convert stored energy to usable power and much more efficient rate than gasoline powered engines. During the combustion process the majority of energy stored within gasoline ends up going out the exhaust pipe. The EPA rates gasoline powered vehicle efficiencies at 15% on average, whereas, they rate electric powered vehicles at an average of 60% to 80% efficiency. What this essentially means is that the Holy Grail of battery energy density is about 1/5 the energy density of gasoline. When we hit that milestone an aircraft would be able to fly equally as well, at the same weights, regardless of flight time. However you look at the data, the one universal truth is, the trend continues in favor of electric powered aircraft into the future. With a little bit of analysis, you can't help but get excited about where all of this is heading.

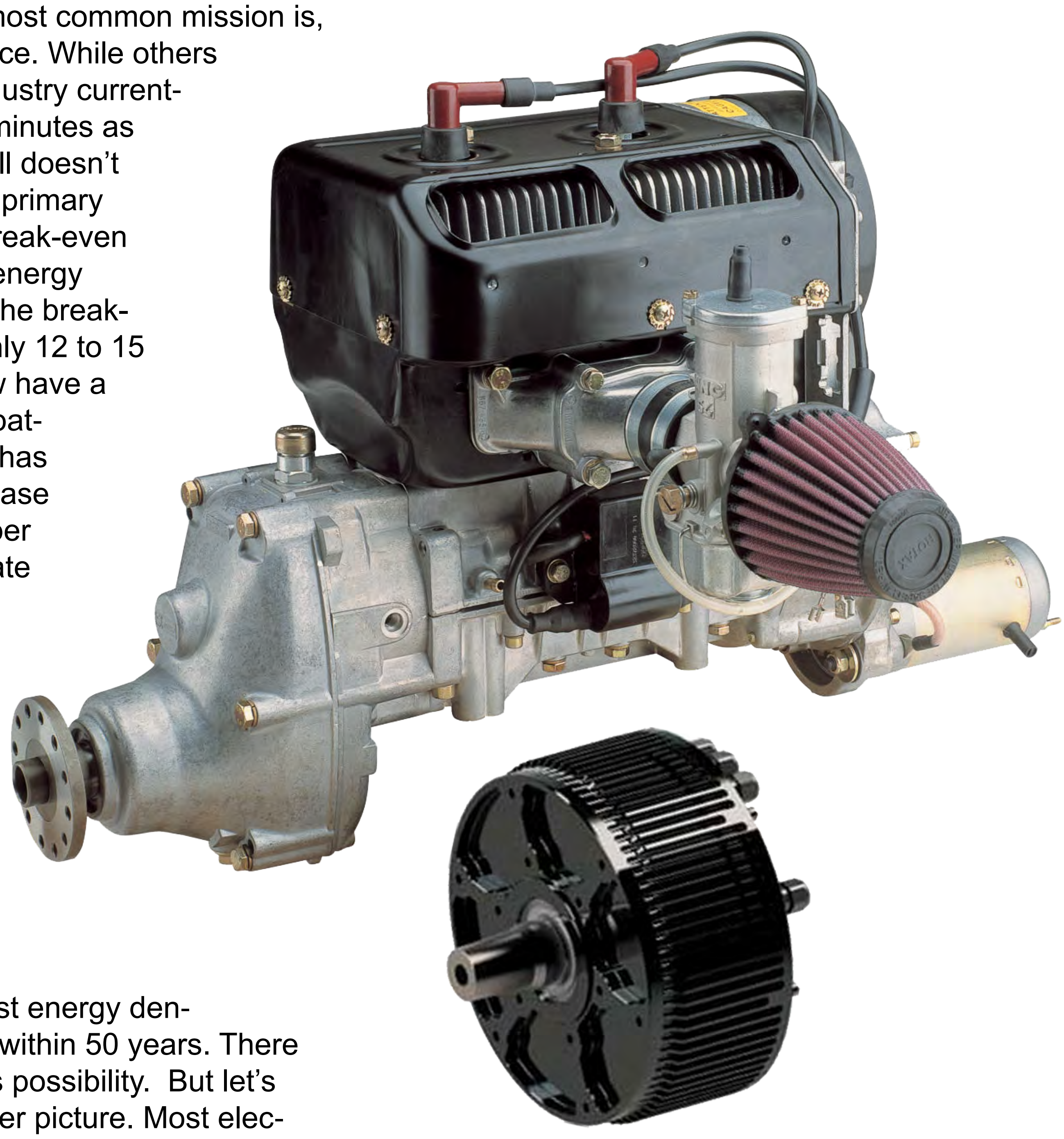


Figure: 1 Two Stroke vs Electric

But back to the more relevant dilemma, the current state of affairs relegating us to this 23 minute flight time paradigm. In the design of the EMG-6 electric motor glider the goal was to leverage these realities and create an aircraft more suited to a mission profile similar to the electric model aircraft paradigm. First, the aircraft would, by necessity, have to be a glider. Airplanes require a 30 minute fuel reserve whereas a glider requires none. Packing around an extra 140 pounds (20% of gross weight) in batteries as dead-weight was ridiculous. A glider, by its nature could take advantage of thermals and ridge lift for its primary lift source, while utilizing the battery for cruise between thermals, or as a sustainer motor in poor lift conditions. In conditions where lift is abundant, we could use regenerative power to recharge the batteries during flight. The ability to be able to use regenerative power, or even thrust reversing to control flight path on approach, would eliminate the necessity for spoilers. Flying locally would allow us to use smaller battery packs, reducing weight, increasing performance and simply changing battery packs in between flights. If we were flying locally, we could simplify the aircraft by concentrating on minimum sink performance rather than glide ratio keeping our design simple and low-cost. Since most of the energy is used up in the climb, having a glider that could be either ground or aero towed to initial starting altitude would allow us to significantly increase the flight time using

Figure: 2 *Author and EMG-6 Electric Motor Glider*

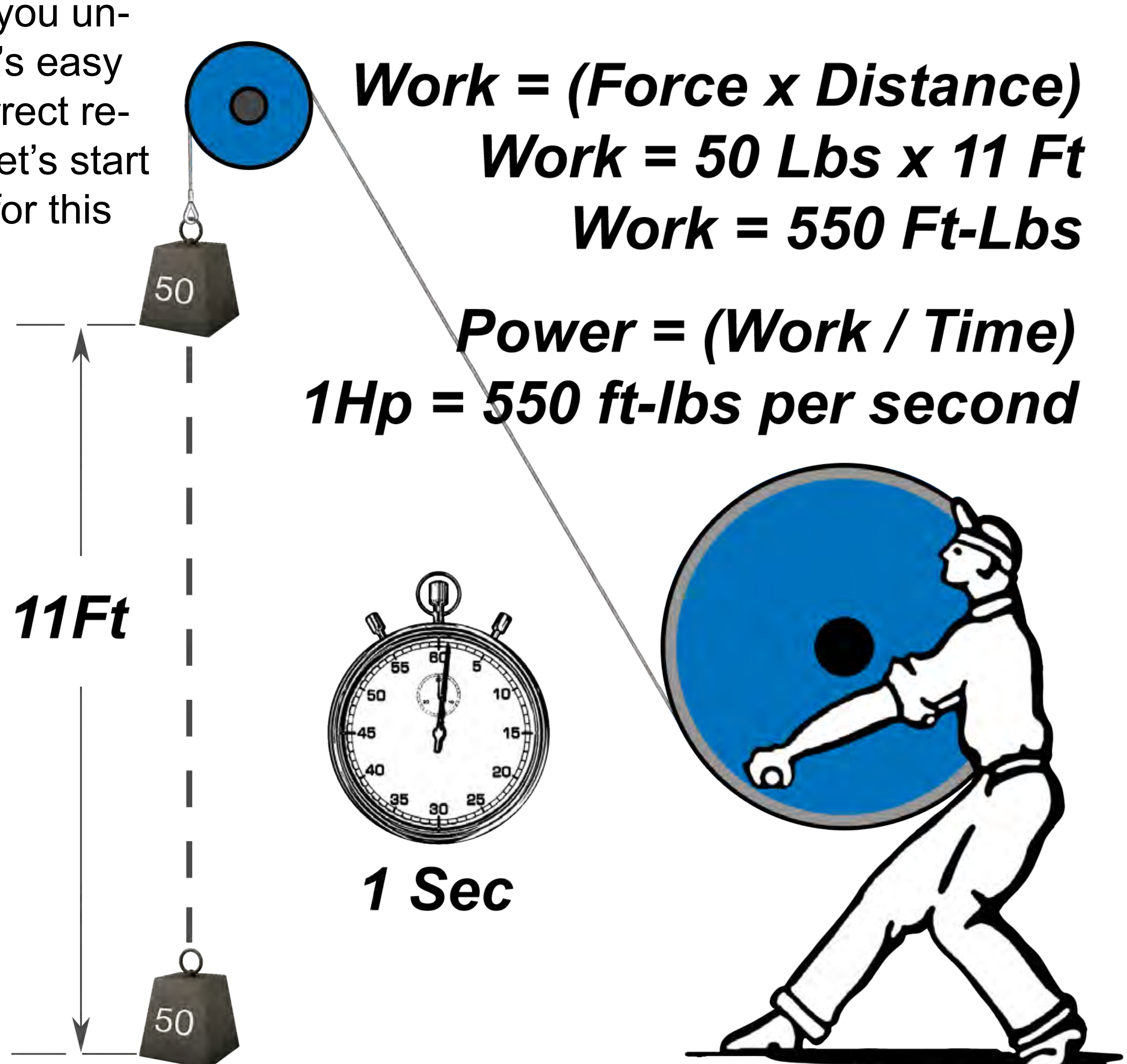
the motor primarily for sustaining flight. As part of our proof of concept of these principles, the original EMG-6 prototype #1 (Figure: 2) was flown over 100 flights using off-the-shelf model airplane technology: motor, controller, propeller, batteries, charging systems, flight data recorders, and instrumentation. We are now on to experimenting with the next generation of electric motors for self-launch capability. Over the last decade while working on this project, we have seen the aviation public perception morph from skepticism to excitement. Every year we see an ever-increasing number of electric powered vehicles including electric powered aircraft.

One of the most exciting aspects of the electric aircraft innovation will come from the ability to leverage the innovation developed in other electric vehicles. Buying electric automobiles and motorcycles from the junkyard, and re-purposing these technologies for utilization in our experimental aircraft. We joke, if you own a Tesla and you see a car on the freeway with the EAA sticker in the window, give them a wide berth. The Tesla batteries are kind of the hot ticket for those of us that are thinking about experimenting with electric systems from the automotive industry. The EAA, out of all the aviation communities, is poised to leverage this technology more than any other segment of aviation. After all, EAA'ers are primarily recreational flyers who love to tinker and innovate. We expect to see a remix within the EAA community similar to the paradigm that is "EAA," started by Paul Poberezny. The entire EAA organization was created by these tinkerers and inventors leveraging other aviation and automotive technologies to build these wonderful things we call home built aircraft.

As flight instructors, there is nothing more rewarding then finally getting to that “aha” moment. Or, as flight instructors refer to it, the fourth level of learning “correlation”. Correlation is known as the highest level of learning where a student is able to combine multiple concepts, processes, and insights previously learned, into a larger whole that leads to that “I get it now” moment.

In our many decades of flight instructing, the richest vein of golden “aha” moments to be mined has always been found in our segment on understanding and managing energy. Understanding how energy affects flying is one of the greatest revelations a pilot can experience. Unfortunately, this is one area that even today, seems to be absent from the majority of flight training syllabi.

Students exposed to these concepts early on, are often surprised to meet other pilots without this same level of understanding. To demonstrate the value, several years back, I took one of our newly minted pilots with less than 100 hours flight time to an EAA fly-in sponsoring a spot landing contest. Bringing home both the 1st and 2nd place trophy really put into perspective the level of “correlation” that had occurred considering only weeks before the student was nervous about passing the impending private pilot checkride. In ground school, we often say (with our typical taint of hyperbole) that it is impossible not to hit the exact spot that you wish on landing. It is simply a math problem. Once you understand the formula, it’s easy to come up with the correct results. That being said, let’s start laying the groundwork for this “formula”.



Energy is defined as “the capacity of a system to perform work”. Work transfers energy from one location to another. Lifting a 50 pound weight 11 feet results in 550 foot-pounds of work being accomplished. In our example,we are using an example of mechanical work. Work can also be accomplished by many other forms including, heat, chemical, kinetic, potential, electrical, nuclear, light, magnetic, and others.

"Power" by definition is the amount of work done in a certain period of time. One horsepower is defined as work done at the rate of 550 foot-pounds per second. If it helps, you can think of power as the rate at which energy is generated or used. In our graphic, you can envision how difficult it would be to raise a 50 pound weight 11 feet in just one second. However, if we were to change the size of our crank pulley allowing for much greater leverage, and give our human power source ten seconds to accomplish the task, the possibility becomes much more achievable. This showing that the same task can be accomplished with 1/10 of a horsepower. Even so, the total amount of work or (energy) is the same in each case.

In physics, the law of conservation of ethenergy states that the total energy of an isolated system remains constant. This law means that energy can neither be created nor destroyed; rather, it can only be transformed from one form to another. In a simplified form, flying an aircraft is an exercise in energy transformation. An aircraft sitting static on the ramp requires the transformation of energy even for the act of taxiing. Our primary source of energy comes from the fuel tank. Gasoline (chemical energy), can be converted to mechanical energy through that wonderful invention the internal combustion engine. Although the efficiency of converting chemical energy into mechanical energy is only about ~30%, the energy density of gasoline still reigns supreme when it comes to moving vehicles long distances.

While moving through the air in level flight, gasoline from the fuel tank is converting ~70% of the energy into heat as a result of the combustion process, the remaining ~30% is converted into mechanical energy via the engine which in turn spins the propeller converting that mechanical energy into thrust used to propel the aircraft (discounting friction and power required to run accessories). As the aircraft speeds through the air, that remaining ~30% of energy is also converted to heat in the form of drag. Additionally, if there is excess power available, it can be converted and stored as kinetic energy in the form of velocity as well as potential energy in the form of altitude. The 50 pound weight in our graphic is an example of converting one form of energy into potential energy. The 550 foot-pounds of work that we had done previously now has the "potential" to create that same amount of work as gravity applies a force to our 50 pound weight. An aircraft that has climbed to an altitude of 10,000 feet now has the potential energy equivalent to the amount of work required to get it to that altitude.

The laws of aerodynamics require that we maintain a minimum amount of airspeed in order to be able to sustain flight. As a result, there is a very specific amount of power necessary to overcome the drag (energy) used by the aircraft at any given speed. Essentially, there are only three sources from which to convert this energy. Fuel (chemical energy), altitude (potential energy), and airspeed (kinetic energy). You can think of each one of the sources as batteries. Essentially, energy storage devices. Each of these sources of energy can be utilized to sustain the miracle of flight. With internal combustion engines we can convert the fuel into potential energy or kinetic energy. And we can convert potential energy into kinetic energy as well as kinet-

ic energy back into potential energy. Now, with the advent of electric aircraft, we now have the exciting possibility of converting either kinetic or potential energy back into "fuel" as well. Each one of these energy sources are contrasted by their storage capacity. At the given rate of power required to overcome the drag in-flight we can now get a corresponding idea of the ability of each one of these energy sources to store energy. The capacity of fuel can usually be measured in hours, whereas potential energy in the form of altitude will generally render only minutes of capacity, and the capacity of kinetic energy stored in the form of airspeed would typically provide capacity measured in seconds.

In level cruise flight potential and kinetic energy remain constant. And the amount of power for thrust equals the amount of drag.

Climb is a function of excess horsepower. To convert fuel into altitude we typically slow the airplane down to Vy (best rate of climb) which will provide less drag allowing more of the chemical energy to be transferred to altitude rather than converting it to airspeed (drag)(heat).

Approach and landing: the goal of each landing is to arrive at the touchdown point with the potential energy (altitude) at 0, the kinetic energy (airspeed) just above stall speed, and the chemical energy (throttle setting) to minimum. We've all seen the pilots that try drive the airplane onto the runway in order to be able to hit the numbers. The fallacy in this concept is that kinetic energy and potential energy cannot be made to disappear but rather only "converted". when you lower the nose of the aircraft you are converting the altitude (potential energy) into (kinetic energy). We really haven't made a big impact on the total amount of energy. The sum of all the sources of en-

ergy dictates the touchdown position. We teach our students to think of the control stick as an energy converter. We would like to arrive at a target position off of the end of the runway with just enough kinetic energy to arrest the rate of descent into a perfect flare and touchdown at a specific point. This amount of kinetic energy is generally achieved by flying an approach speed in the neighborhood of 1.3 Vso. You have probably heard this referred to as a stabilized approach. Because the landing is generally a judgment on managing the total energy, by stabilizing one of the three variables, we are able to visualize the results of the other two sources of energy.
In a stabilized approach, the aircraft will establish a trajectory that can be identified easily some distance from the runway. Small adjustments to power can compensate for incorrect a judgment. And with practice, the necessity for adjustments becomes progressively less. Arriving at a specific location and altitude just off the end of the runway coupled with a very specific airspeed is a finite amount of energy. Pile driving the nose onto the runway or holding the airplane off in a proper flare still results in the same amount of energy. If you find the airplane floating down the runway uncontrollably, more likely than not, you arrived with too much kinetic energy. As your flight instructor has probably told you, a good landing is generally result of a good approach.
Pilots generally feel more comfortable landing on long runways. On a long runway even if you arrive with excessive kinetic energy holding the airplane off the ground until the energy dissipates still leaves plenty of distance for landing. When you start thinking of the landing as an exercise in managing energy and you are able to arrive at a target point before the touchdown zone with the right amount of kinetic energy you can’t help but nail the landing. Now that we have discussed some of the basic principles associated with managing energy in-flight we have the foundation which will allow us to take the discussion to and entirely new level. In part 2 we will explore some very interesting phenomenon related to the management of energy in high drag low mass type of aircraft.

High Drag – Low Mass Aircraft

We first started using the term “high drag - low mass” aircraft, in our first book “A Professional Approach to Ultralights” written back in 2003. Since this term is the topic of this article, we should begin by elaborating on its definition. An “ultralight aircraft”, although not a fully inclusive definition, would probably be a categorization of aircraft that you would most closely identify as having the characteristics of a “high drag-low mass aircraft”. These aircraft have operating characteristics that set them apart from “traditional” aircraft. And, as a result, we continue to see unintentional accidents at a frequency that leaves us with a desire to address the subject matter. In our area, we recently saw this scenario play out once again. A Quicksilver GT-500 with student and instructor on board, suffered an engine failure shortly after takeoff (approximately 100 ft) in the middle of a 6000 ft runway. And, although injuries were only minor, the aircraft was destroyed. Engine failure aside, the primary reason for the subsequent crash, was a simple unfamiliarity with energy management protocols for these type aircraft. These type of accidents occur almost exclusively as a result of an engine failure. As long as the engine continues to produce thrust, we can overcome the inherent drag of the aircraft design, and for all practical purposes, make the aircraft respond and perform like a more traditional aircraft.

In our previous article, we addressed the subject of energy. In particular, the process of converting chemical energy (fuel) into kinetic energy (airspeed), potential energy (altitude), and heat energy (drag). In this article, we are addressing what happens after the engine quits. This essentially means

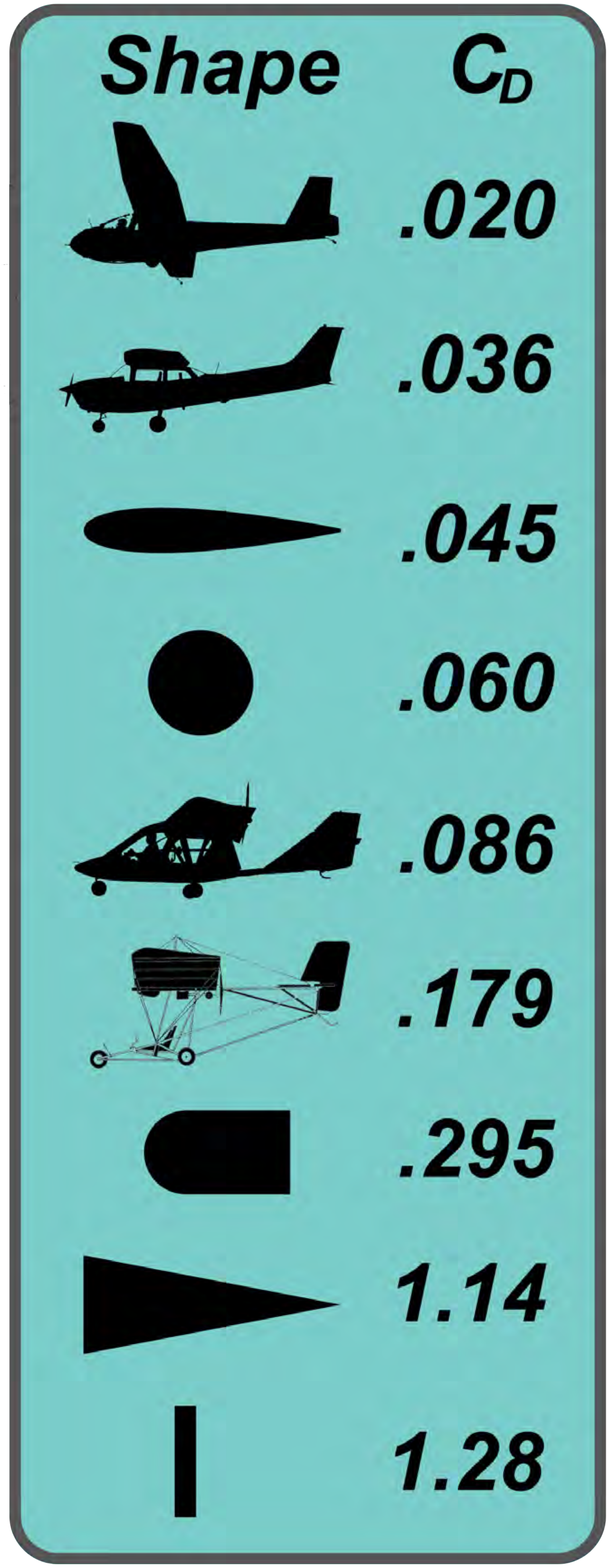


Figure: 1 Shape / Coefficent of Drag

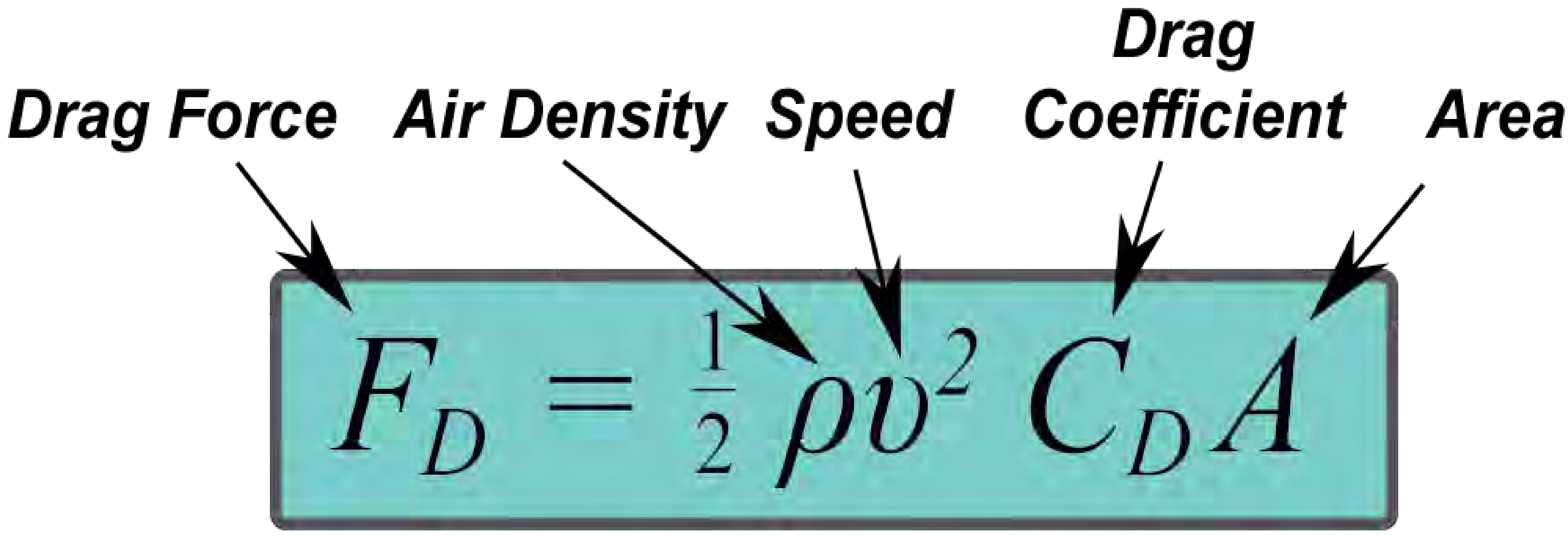


Figure: 2 Drag Formula

that we are now dealing with only three forms of energy. The energy that is stored as potential and kinetic energy. And the constant "sucking" of that energy in the form of drag to maintain airspeed. It's often difficult to wrap our minds around really how much drag is on a particular aircraft. If we look at the formula for calculating drag figure (Figure: 2), we can see that it isn't really all that complicated. For a given velocity and air density it is really the (size (A) of the object or aircraft) x (the shape of the object (drag coefficient)) that determines the total drag force. The coefficient of drag is a dimensionless variable generally derived from wind tunnel testing to account for the many nuances of drag as a result of very complex shapes and interactions with the air.(Figure: 1) It is helpful to be able to visualize the difference that the coefficient of drag makes on the total drag. In our graphic we can see that, if all other things are equal, there would be nearly nine times the amount of drag on our ultralight compared to the basic glider. In Thurston's book "Design For Flying" he gives us two formulas for the layperson that become helpful in understanding drag. (Figure: 3) The premise for these formulas is the principle that in unaccelerated flight, thrust equals drag. Using a conservative propeller efficiency of, let's say, .75 at maximum power, we can now extract an approximation of both the coefficient of drag total, and the total drag opposing thrust. When we look at these high drag low mass aircraft closely,

$$C_{D_{Total}} = \frac{(\text{horsepower})\,(\text{prop efficiency})\,(146{,}620)}{(\text{wing area}_{\text{sq ft}})\,(\text{maximum speed}_{\text{mph}})^3}$$

$$\text{Drag}_{\text{lbs}} = \frac{(\text{horsepower})\,(\text{prop efficiency})\,(375)}{(\text{maximum speed}_{\text{mph}})}$$

Figure: 3 Thurston's Formulas

we recognize immediately that the ratio of drag to mass leaves us with a scenario similar to that of our golf ball graphic. Our white golf ball, a regulation 45.9 g golf ball, leaves the tee at the same velocity as our practice golf ball weighing in at only 10 g. The kinetic energy is quite different in each case, both golf balls exhibit the same drag coefficient as they are both identical in size and texture. However, the kinetic energy imparted to the regulation golf ball is significantly higher.(Figure: 4) Remember, Newton's first law of motion states that, a body in motion remains in motion until acted upon by an outside source. We normally refer to this as "inertia". In our golf ball example, the force that is absorbing this kinetic energy is drag from the air and friction along the ground. Both the distance and the time until both golf balls are at rest is also quite different. And like our golf ball example, the ultralight versus traditional aircraft scenario is similar but with a few nuances that make the situation even more critical.

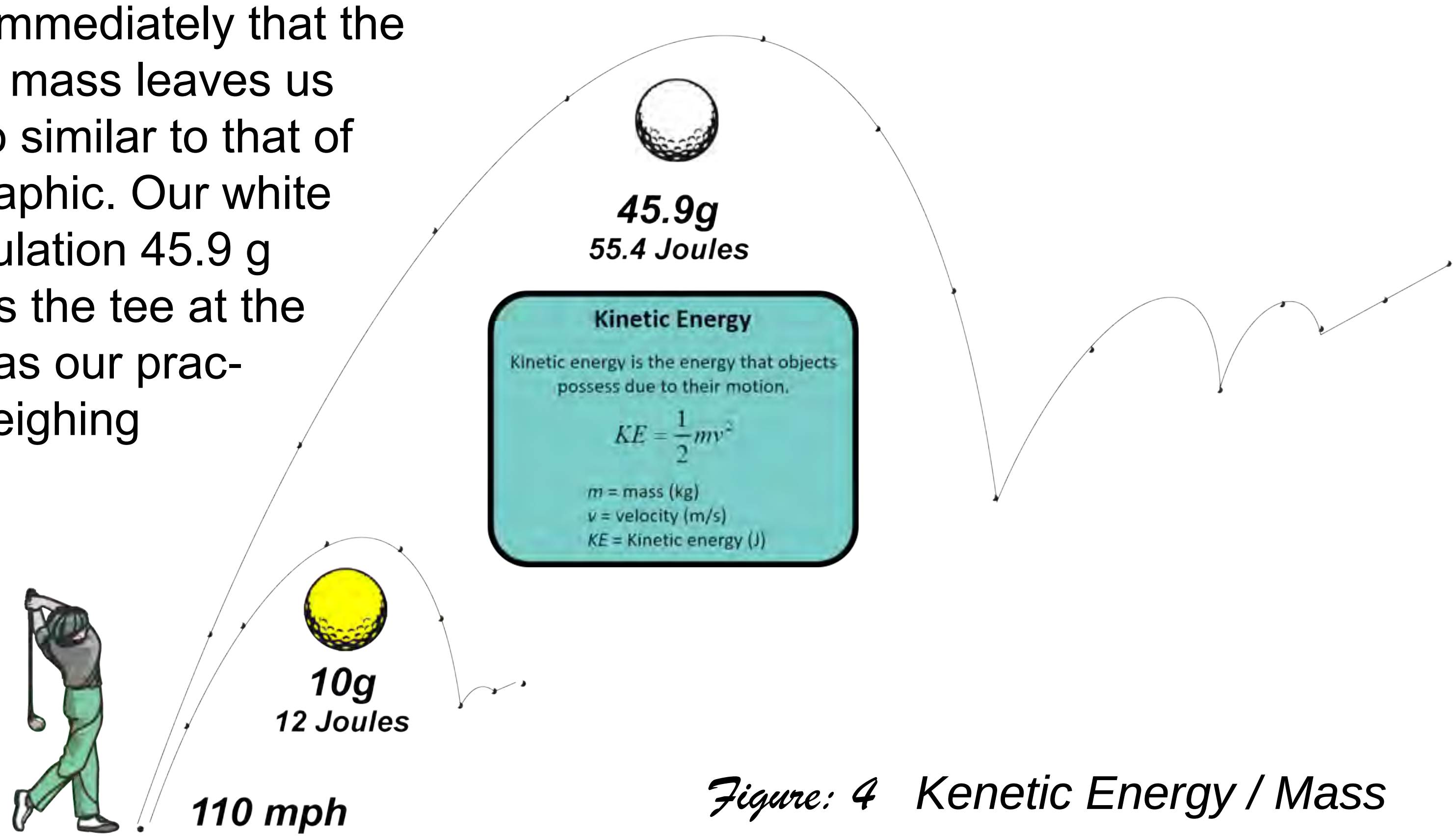


Figure: 4 *Kenetic Energy / Mass*

Let's walk through what we refer to as the Vx dilemma.(Figure: 5) There is an angle of climb on many of the high drag low mass aircraft that results in a situation that is nonrecoverable in the event of an engine failure. No matter how proficient the pilot, the math does not support the possibility of a successful outcome! Position 1: engine failure. It may take the average pilot a few seconds to register what has happened in the event of an engine failure,

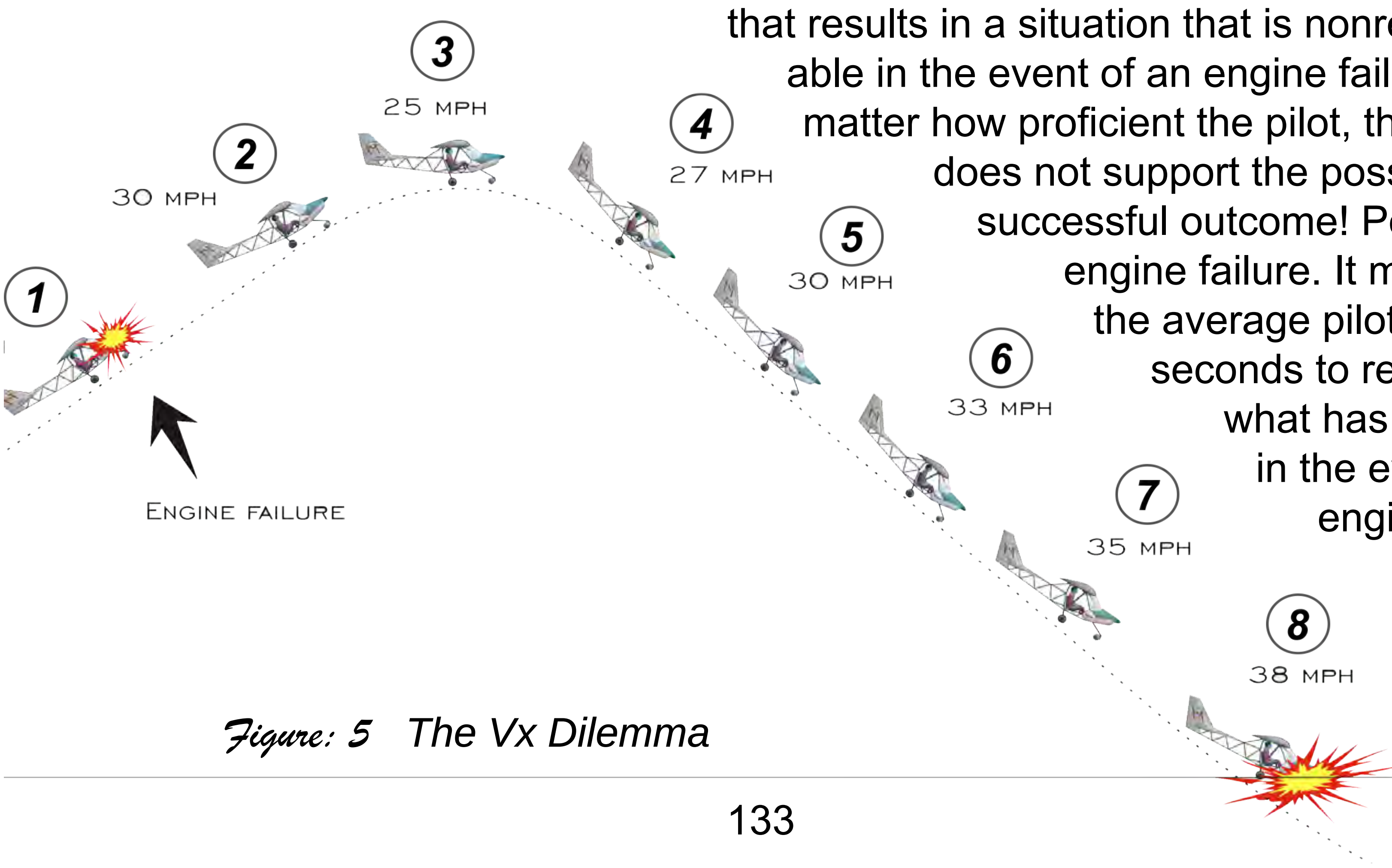


Figure: 5 *The Vx Dilemma*

but even with an expert pilot responding instantaneously, we have several things going against us in this scenario. Because of the loss of thrust the aircraft begins to slow rapidly. Additionally, the aircraft is headed uphill, converting what little kinetic energy there is in to potential energy. On the climb the aircraft is already fairly high up on the coefficient of lift curve, and even with a quick response and aggressive pushover, within two seconds we may be able to start rounding the apex of the curve, but at this point we have dissipated all excess kinetic energy and we are at 16° to 18° angle of attack. The drag in this configuration goes up even more. If we allow the aircraft to sustain this angle of attack, our optimal glide ratio of 5.5:1 would be more in the neighborhood of 2:1. If we continue to push over hard in order to be able to lower the angle of attack, we can start to convert the altitude back into airspeed. However, it's not quite as easy as it might at first seem. Because of the high drag configuration the ability to convert altitude back into kinetic energy is a bit difficult. Think of dropping a feather, (the ultimate example of high drag low mass) terminal velocity is reached literally within a few seconds. It's not that bad, but feeding the "drag beast" requires an exceptionally low nose attitude and "time" to convert the altitude into airspeed. With an engine failure at 100 feet AGL, we have neither. Looking at the airfoil data chart,(Figure: 6) you can start to get an understanding of the necessity to arrive at the runway with additional energy. Starting the landing round out and flare at 2° angle of attack (represented in green) results in a fairly significant increasing coefficient of lift with a moderate increase in drag with

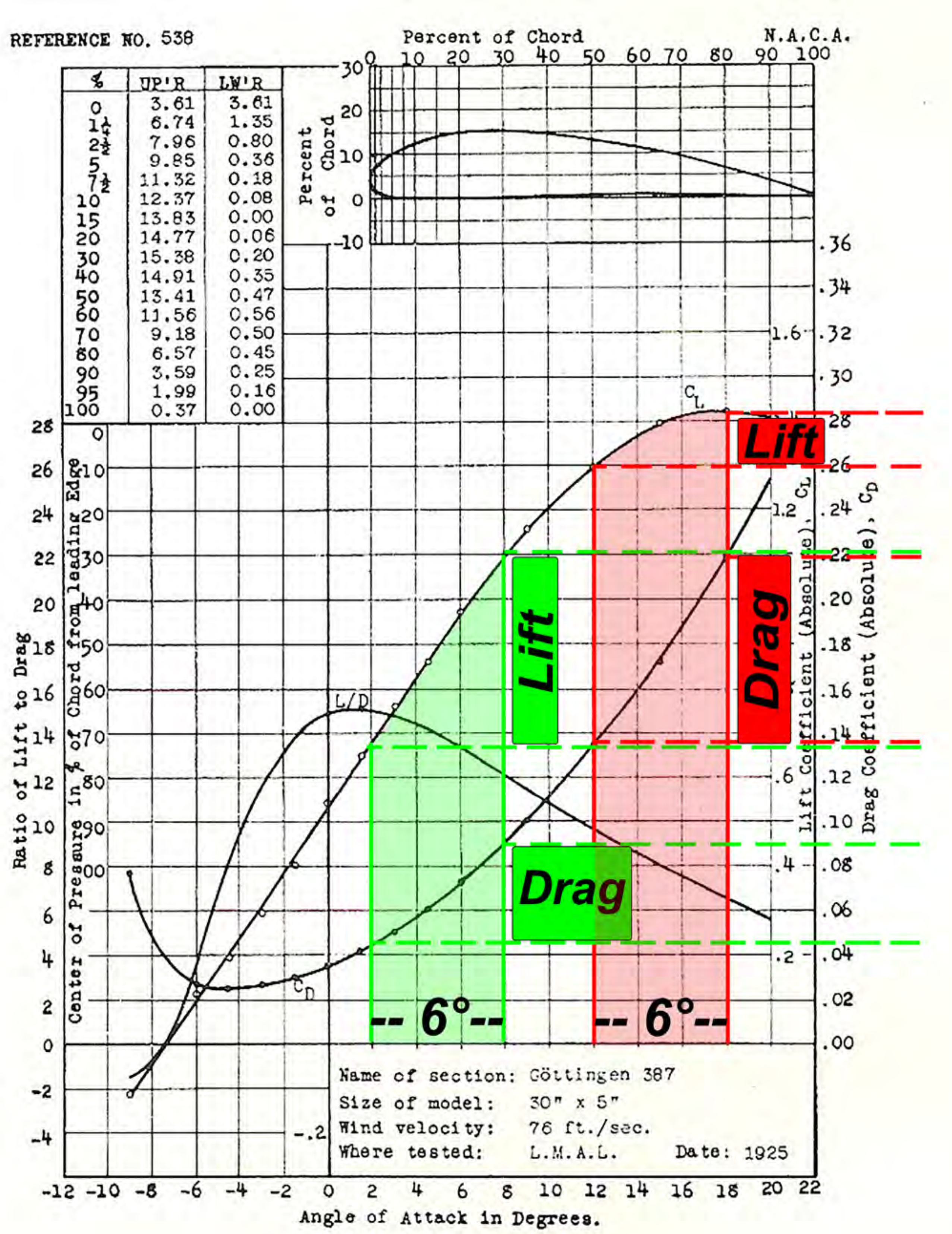


Figure: 6 Angle of Attack vs Drag

just a 6° pitch change. Starting that 6° pitch change at 12° results in a tremendous amount of drag increase with virtually no significant increase in lift. This is that area that you may be familiar with, that is often referred to as the “mush”. Same pitch change but virtually no increase in lift and a significant increase in drag. The solution to the problem is actually quite simple. However, just talking about it and explaining it, isn’t sufficient. The “site picture” in these aircraft is really quite different than a traditional aircraft. That site picture is exacerbated in an emergency situation. The time interval, like the practice golf ball, is very short. It is nearly impossible to be successful without having first practiced the engine off scenario. The most common error made by transitioning pilots, is to start the flare to soon. Even arriving at transition point with the normal amount of airspeed leaves us with only enough kinetic energy to effect a round out and flare lasting only 3 to 4 seconds.(Figure: 7) If you’re going to arrive at the runway with the minimal amount of energy you’re going to have to time it absolutely perfect. In practice, we have the engine to save our butt. And that’s the purpose of training. We have a saying, “you can’t do it till you’ve done it”. It usually takes less than an hour of transition training to make a traditional aircraft pilot competent. It’s not hard, it’s just different. Really, really different. If you are a pilot that flies a high drag low mass aircraft you already understand what we are talking about. And you also know one other secret about these type aircraft. They are some of the most enjoyable aircraft to fly.

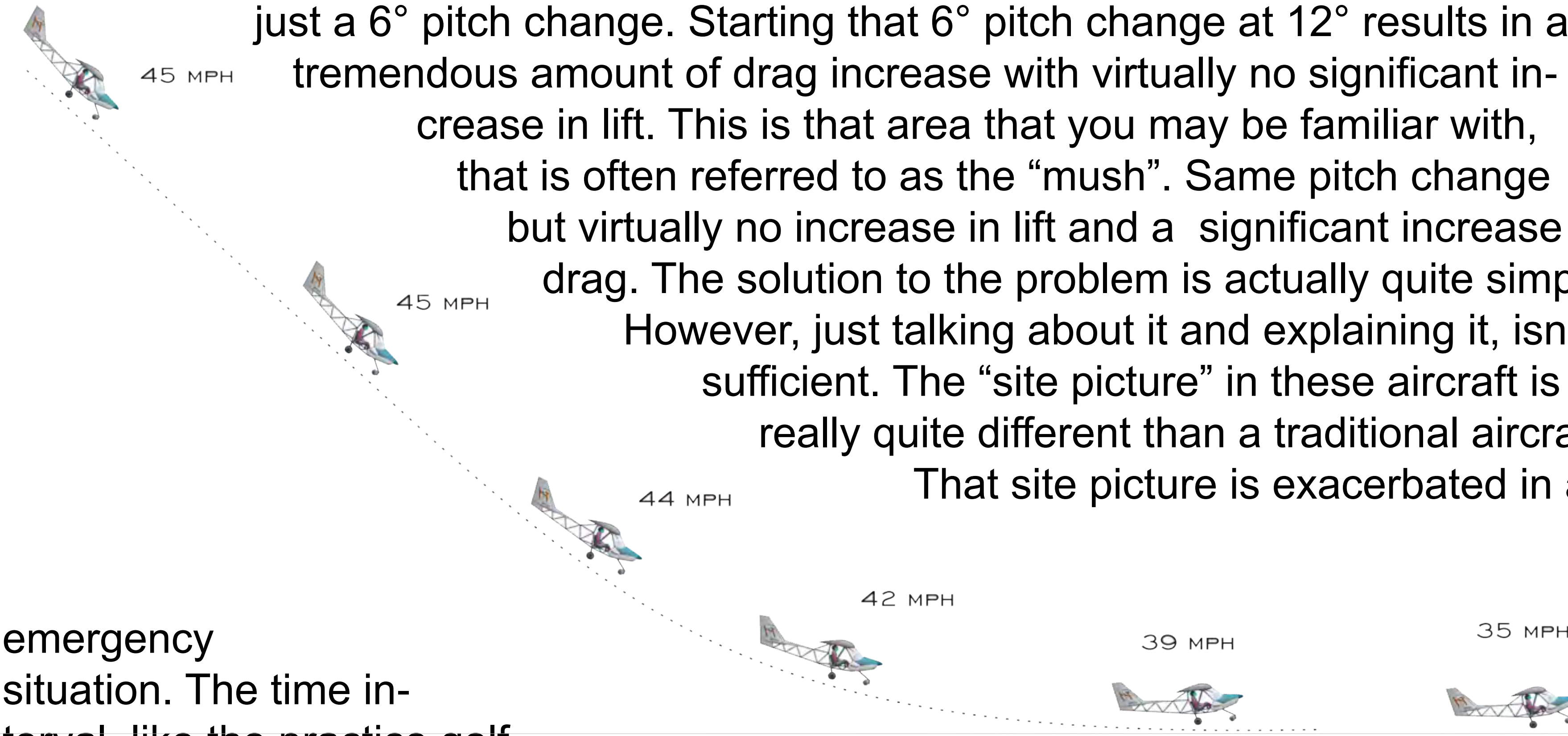


Figure: 7 *Transition to Flare*

Have you ever noticed, that when you go to work on your airplane, you'll always reach for that favorite screwdriver, wrench, or ratchet from your toolbox. It just works better. Working with good tools makes the job enjoyable whereas working with inadequate tools is just frustrating. Worse yet, is trying to accomplish a job without the proper tool to do the job. This is the reason that professional mechanics seem to have a tool for practically every possible scenario they may encounter. The time wasted "dinking" around without the right tool is far more costly than the actual purchase price of the tool. Being prepared and having the right tool ahead of time is what differentiates the professionals from the amateurs. As professional mechanics, we often look at tools from the perspective of how they might function for us in the future even if we have no immediate use. This was the premise behind how we acquired our most recent gadget, the FLIR camera adapter.

(FLIR) stands for forward-looking infrared. Infrared radiation (IR) is electromagnetic radiation (EMR) with longer wavelengths than is typically invisible to the human eye. Infrared radiation is more commonly known as "heat radiation". Thermography is an infrared imaging technique, using specialized sensors to detect radiation in the long-infrared electromagnetic spectrum for taking photographs or video. Modern digital cameras utilize a CMOS (complementary metal–oxide–semiconductor) sensor which has most of its spectral sensitivity focused in the visible light wavelength range. Similarly, a thermo-graphic camera uses an FPA (focal plane array) sensor that responds to the longer wavelengths associated with infrared radiation. The newest technologies use low-cost "microbolometers" as FPA sensors. A microbolometer works with infrared radiation in wavelengths between 7.5–14 μm. The infrared radiation strikes the detector material, heating it, and thus

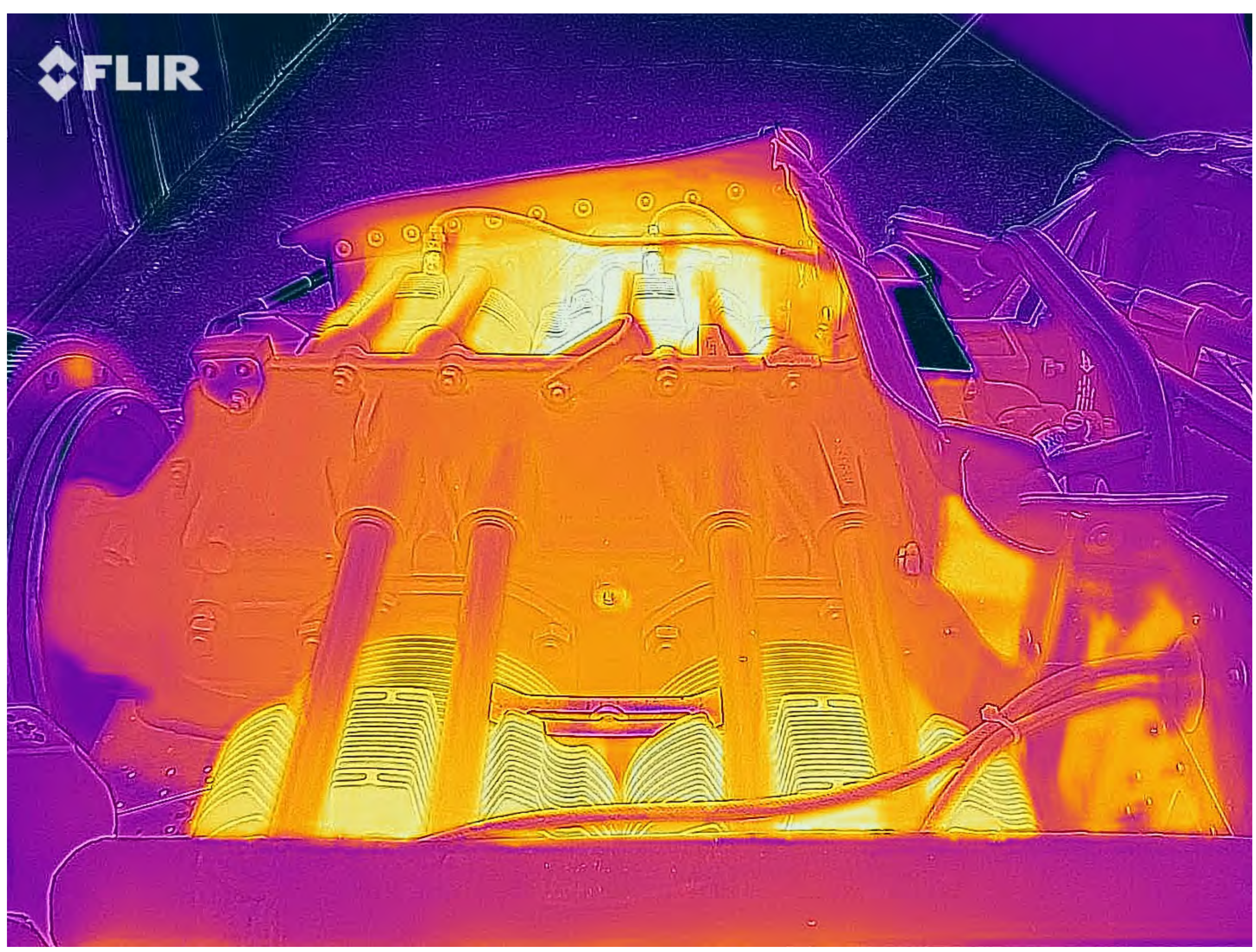


Figure: 1 FLIR Image of Lycoming 0-320 changing its electrical resistance. This resistance change is measured and processed into temperatures which can be used to create an image.(Figure: 1) We have all seen the videos of the FLIR equipped military or police helicopters following the bad guys in the dark of night with contrast rivaling daytime photography. The clarity of the image is really quite remarkable. For the last couple of years we have now been utilizing this same technology in the shop for troubleshooting and maintenance tasks with surprisingly positive results. In the past, these types of cameras would typically cost in the neighborhood of $2000 for even the cheapest version. However, in recent years there has been a significant up-tick in the number of manufacturers making FLIR camera adapters for smart phones. By utilizing the smart phone computing power along with the high resolution screen, the cost to convert your phone into an IR camera has become much more affordable. A while back we purchased a “FLIR ONE” professional IR camera adapter costing around $400. And today there are many of these same type of smart phone IR cameras costing less than $200. This adapter has the ability to measure temperatures between -4°F and 752°F (-20° to 400°C). The manufacturer of this camera has combined both a visual camera along with a 160 x 120 thermal camera. (Figure: 2) The advantage of this is that it provides a proprietary process called MSX which embosses visible edges from the 1440 x 1080 HD camera onto thermal imagery to create a sharper, easier to understand picture. (Figure: 3) This is particularly helpful when you’re trying to pinpoint the source of a specific problem.

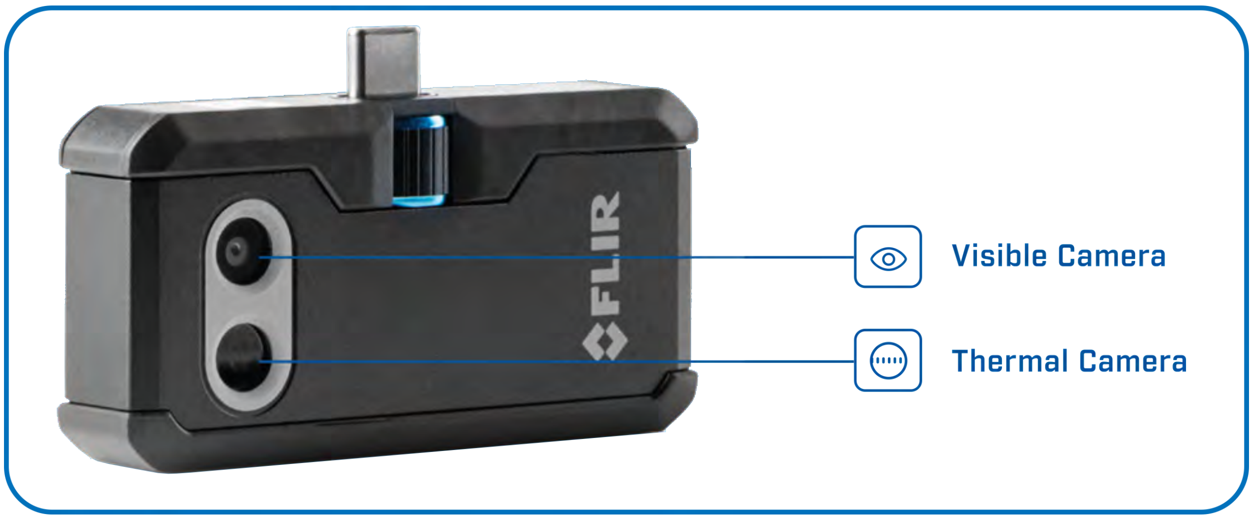


Figure: 2 FLIR ONE Smart Phone Adapter

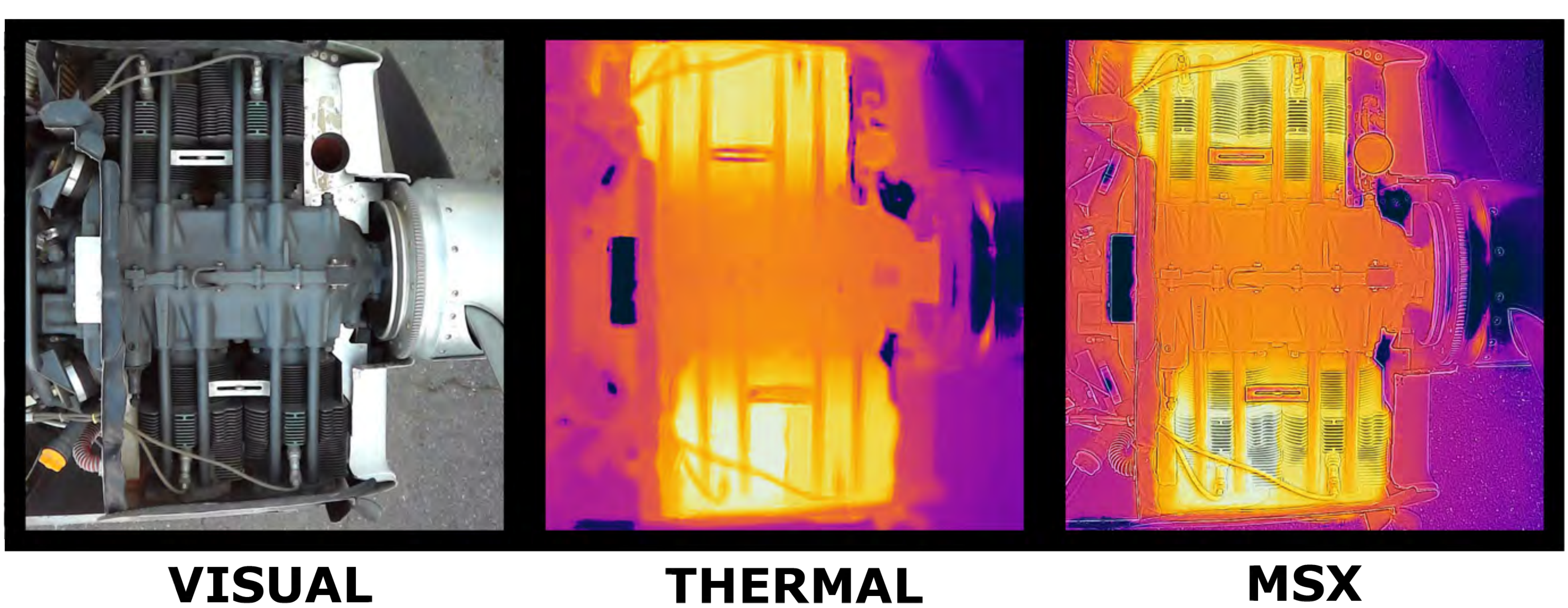


Figure: 3 Thermal Imagery with Visual Overlay

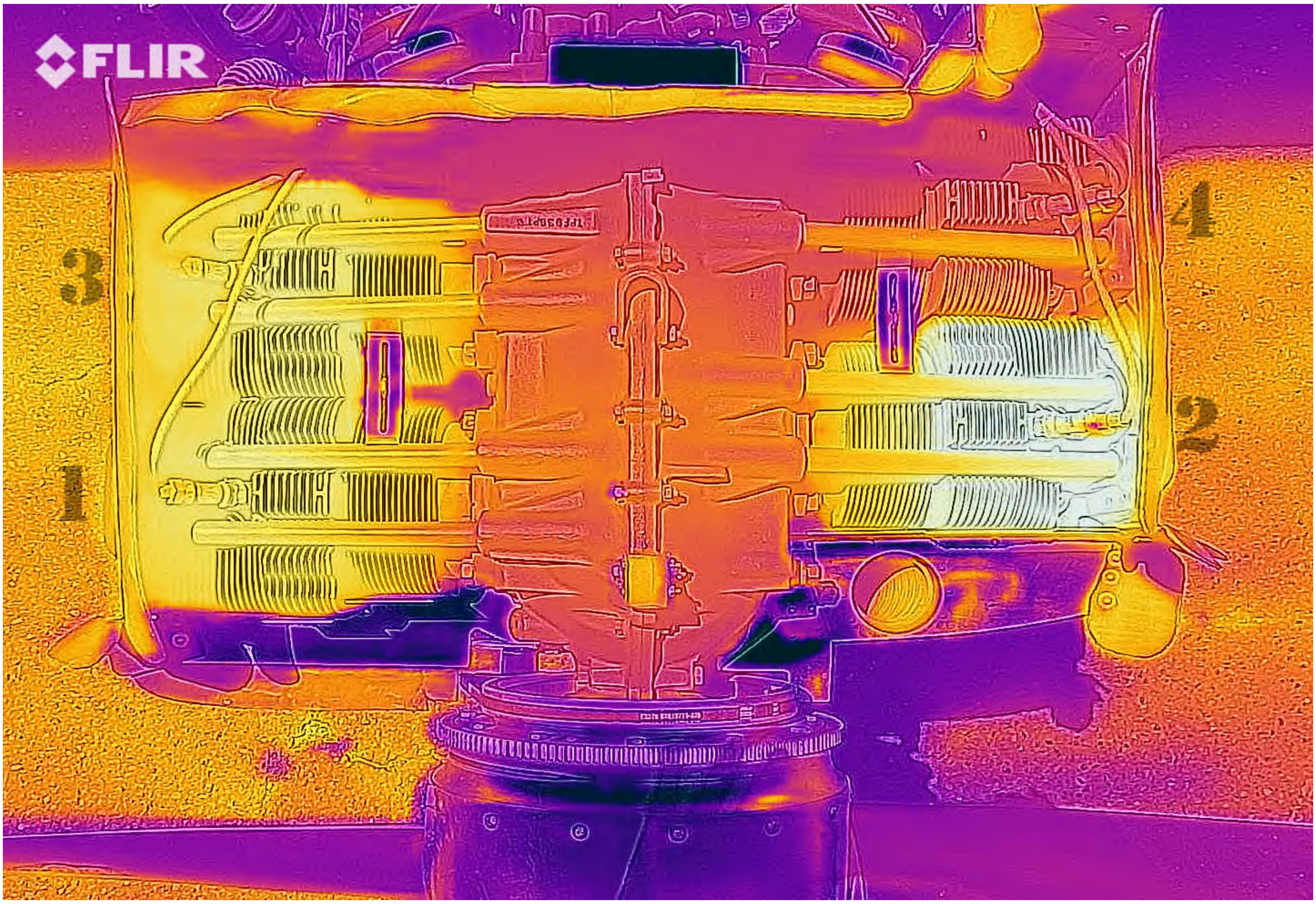


Figure: 4 #4 Cylinder (Cold) #2 Cylinder (Hot)

The power plant on an aircraft is simply an energy converter. Chemical energy (fuel) is converted into heat energy (combustion) which is in turn converted into mechanical energy (torque). Being able to visualize the heat within an engine can reveal a lot about its operation. Although an unusual condition, (Figure: 4) shows an example and heat signature of an engine with two fouled spark plugs on #4 cylinder (left rear). This shows the dramatic difference in temperatures after only five minutes of run time. We have found the FLIR camera to be helpful in a myriad of similar scenarios while working in the shop. As a result, an aircraft that arrives for an annual inspection will typically get a series of thermal pictures taken of the engine, engine compartment, as well as the cockpit area immediately upon arrival. This provides us with an entirely new layer of information when determining the health of the aircraft.

Although we had started writing this article back in May, the outside air temperatures had consistently started to exceed 100°. Having heat from the engine compartment penetrating into the already high temperature cockpit can get rather annoying. As a result, we took one of our Varga Kachinas flying one night to see if we couldn't pinpoint the source of the additional heat in the cockpit. (Figure: 5) The thermal image showed that the firewall blanket, overall with a few exceptions, was doing a fairly reasonable job. On the other hand,we were able to identify the primary source of the problem to be the air valve for the cabin heat. While in the air, we took thermal pictures of the entire cockpit for evaluation. The FLIR One camera allows for multiple spot temperature indicators to be overlaid onto the photograph (Figure: 6) as well as the option to evaluate the overall temperature of specific areas. Out of all the Garmin radios, the transponder appeared to be the hottest. However, using the spot temperature indicator revealed the face to be a comfortable 87.9°F. This is just one example of our most recent utilizations of the FLIR camera. Let's review a few of our other past utilizations that have proven to be quite effective.

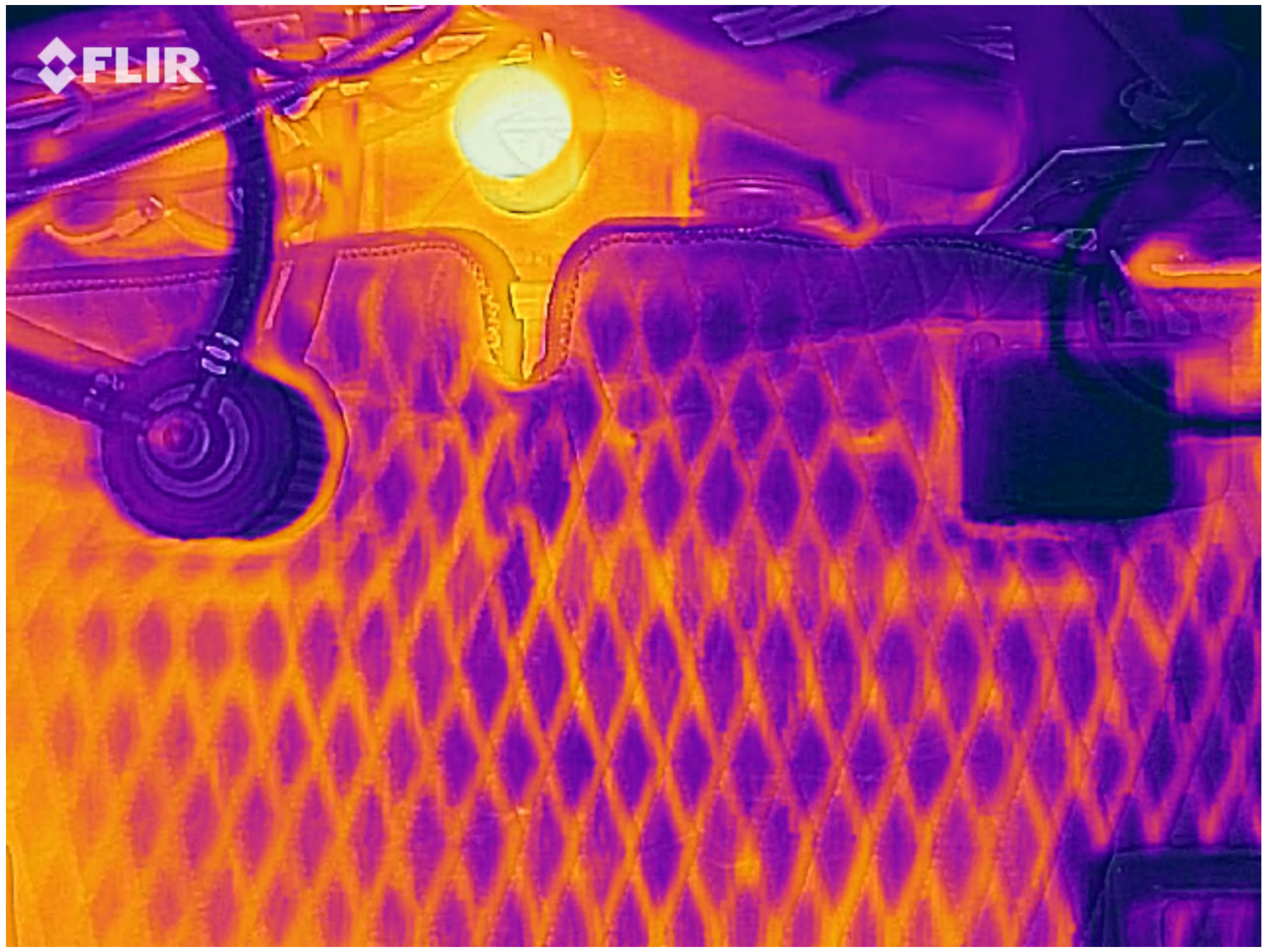


Figure: 5 Heat signature from Varga Kachina Firewall

Exhaust systems: The high temperatures encountered in the exhaust system can reveal a whole range of potential problems. A crack in the exhaust system shows up readily during an engine run. Leaks in exhaust clamps, ball joints, or base gaskets are also easy to detect. You can even take a picture of the aircraft with the cowling on and see areas where the exhaust is transferring heat into the cowling. This is particularly useful with a composite aircraft. Having excess heat transferring into the fiberglass cowling can lead to premature degradation of the composite structure.

Electrical systems: This is one area where the FLIR really shines. You can isolate the entire electrical circuit by simply turning on the circuit (applying a load), and then use the FLIR to see the individual wire or circuitry that is heated from the load. You can even see right through upholstery. A quick glance at the circuit breaker panel and you can identify hot-spots. Wire sizes that are too small for the size load will show up brightly in comparison to a larger wire with a small load. High resistance connections at butt connectors and ring terminals attached with screws that have high resistance connections as a result of corrosion can easily be identified as hot-spots. We have used the FLIR camera to troubleshoot cooling issues for generators, and alternators. The voltage regulators on the Rotax 9-Series engines are notorious for failing when overloaded and in particular when inadequate cooling supply is available. Instrument panel and avionics overheating due to inadequate cooling is common place. Being able identify, make modifications, and evaluate the cooling results is paramount to longevity of that gold mine installed in the instrument panel.

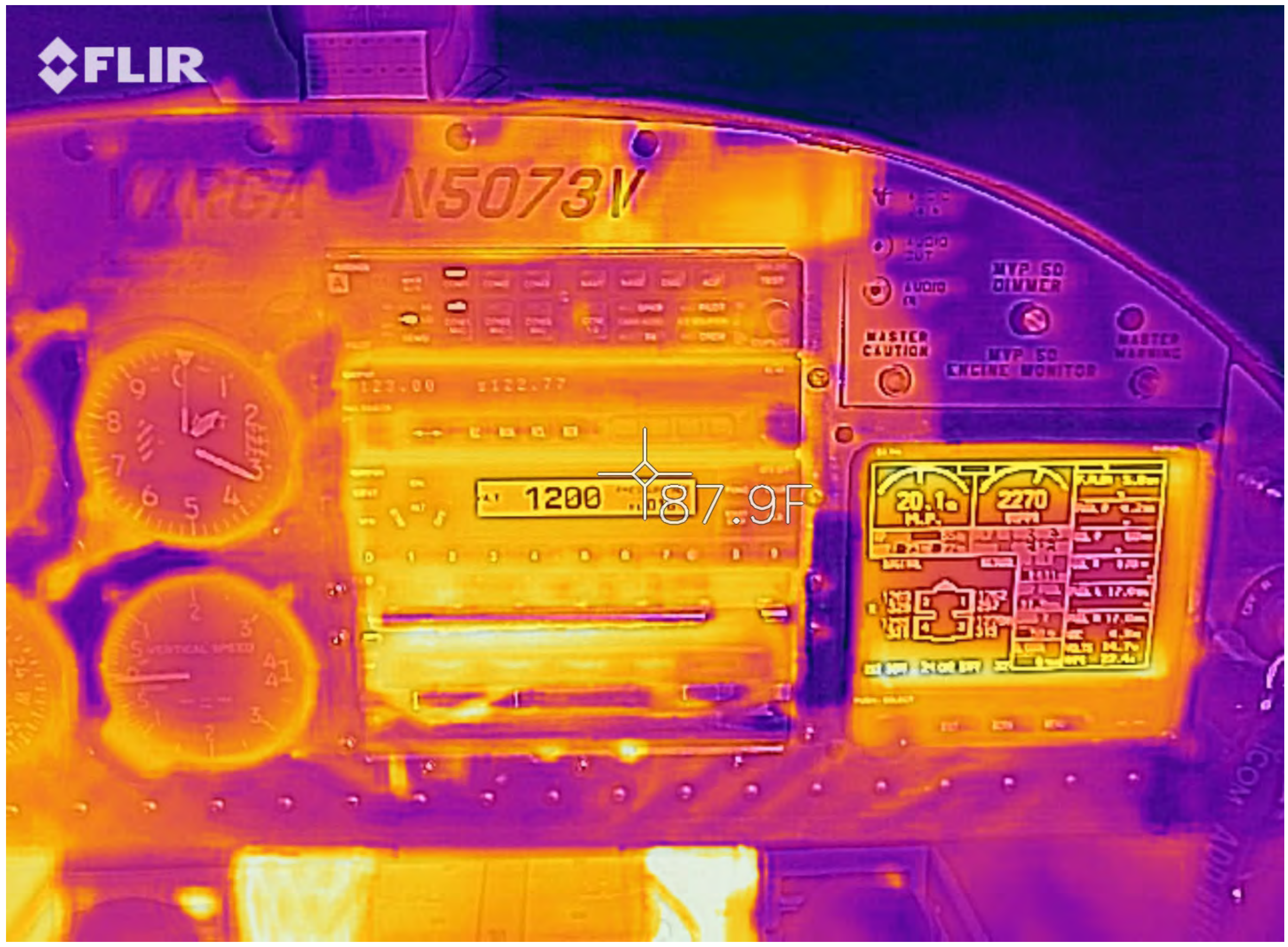


Figure: 6 Built-in Spot Temperature Sensors

Firewall Forward: Checking engine cooling and baffling is probably the single biggest purpose for the FLIR. If the cowling is removed shortly after landing, the residual heat within the engine will give a good representation of the heat distribution throughout the engine. Hot spots are easy to identify and subsequent maintenance to related baffling can significantly improve the engines cooling system. Radiators and oil coolers will instantly show areas of blockage or contamination internally. Following engine hoses will give you a consistent color throughout the entire length of the hose making it possible to literally watch where the coolant or oil is flowing.

Airframe: Not only is it possible to see where the heat is getting through the firewall, it is also possible to see where the cold is entering the airframe during those cold winter months. A quick scan around the cockpit in-flight will generally yield many areas that can be improved to retain the heat within the cockpit. Door and canopy seals, missing insulation, and holes to the exterior are common culprits.

Wheels and Brakes: Overuse of brakes can be identified by following the heat in the brake line, brake calipers, the wheels, and even into the bead of the tire. Wheel bearings with improper lubrication or in the process of failing can be identified.

In all fairness, we are the epitome of gadget junkies. Any excuse to try out new technology is considered a good enough excuse. And over the years, we have had our share of gadgets that simply were not worth the effort or cost. The FLIR smart phone adapter is one of those gadgets that, over time, has kind of grown on us. The more that we use it, the more that we find it to be a useful tool. And, although, the FLIR does not meet the definition of a must-have tool for the average aviator, even at the $400 price tag, we are happy to have invested in one for our toolbox.

When we say the word "hose clamp," most of us think of the traditional slotted, worm drive hose clamp. (Figure: 1) This, by far, is the most prolific style of hose clamp used on experimental aircraft, and it is generally because they are economical, reusable, and come in a wide variety of widths as well as clamping ranges. Having the ability to run down to your local "National Aerospace Parts Association" (NAPA) store and pick out the perfect size clamp for your current project makes it an easy go-to choice when securing low pressure hoses. And although these type of hose clamps are adequate in many circumstances, often times, there is an alternative that will do the job just a bit better for your particular application. Let's look at some of the reasons behind choosing a different type of hose clamp.

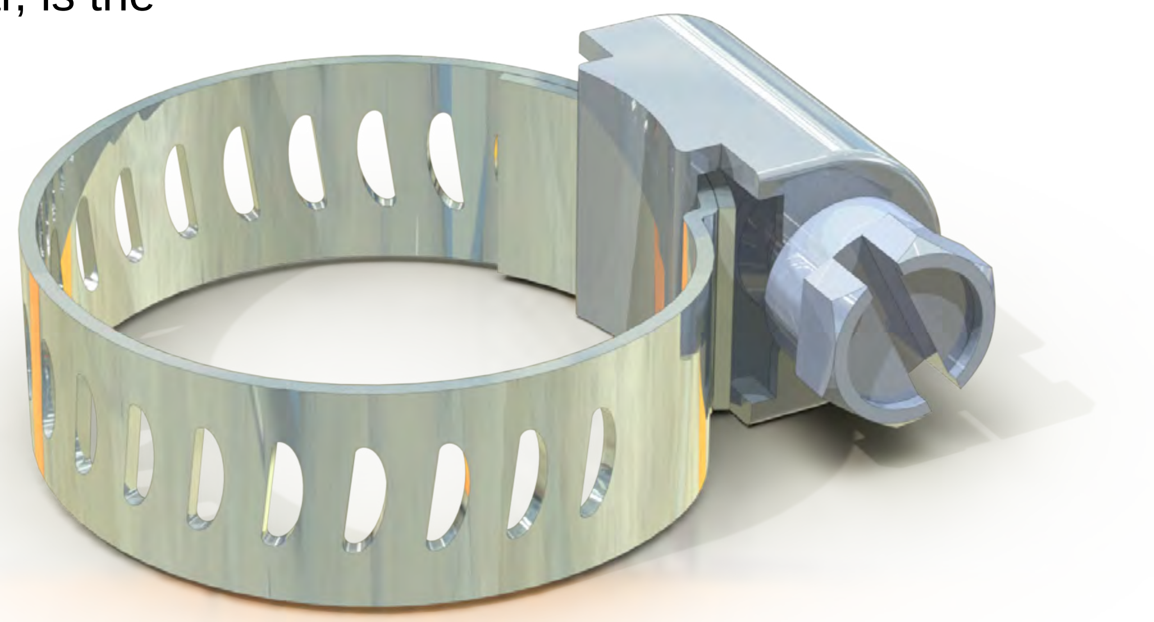


Figure: 1 Worm Drive Hose Clamp

One of the most notorious complaints surrounding the worm drive style hose clamp is that the slots in the band allow the rubber to extrude through the slots when tightened onto the hose.(Figure: 2) This not only degrades the hose outer protective layer, but also prevents the clamp from riding smoothly over the hose during the tightening process. This interlocking of the rubber with the band slots creates a resistance to sliding, and as a result, requires a higher installation torque in order to distribute the clamping force evenly on to the hose. Fortunately, there are a couple of solutions to prevent just this condition.

Figure: 2 Rubber Extrusion Through Worm Clamp

Using a worm drive clamp with an extended internal tail is one solution. These hose clamps provide a sliding internal extension that protects the hose from exposure to the slots in the band. (Figure: 3) Another option is to use what we call and embossed clamp. Instead of having slots cut completely through the band itself, the slots are pressed into the clamp. (Figure: 4) These type of clamps also have roll-formed edges that provide a radius rather than a sharp edge to minimize the damage to the outer hose material. Both of these types of clamps are preferable when dealing with soft rubber or silicone hose. All of these types of clamps work great on very low-pressure systems like the cabin heating and cooling ducts. Or the SCAT hoses used to direct cooling air over the oil cooler. The pressures within these systems are small enough that even with large diameter hoses the clamps can distribute enough pressure to keep them firmly in place. However, all these worm drive / band style hose clamps, and in particular the embossed type clamps, have limitations on how much torque you can apply to the worm gear before stripping out the grooves on the band clamp. As the pressure requirements and hose diameters increase, we get closer to the limitations that these types of clamps can handle. For example, using a worm drive clamp on a turbocharger or intercooler boot connection would likely result in a failure at the connection. This is typically where we opt for a bolt and nut type of band clamp. (Figure: 5)

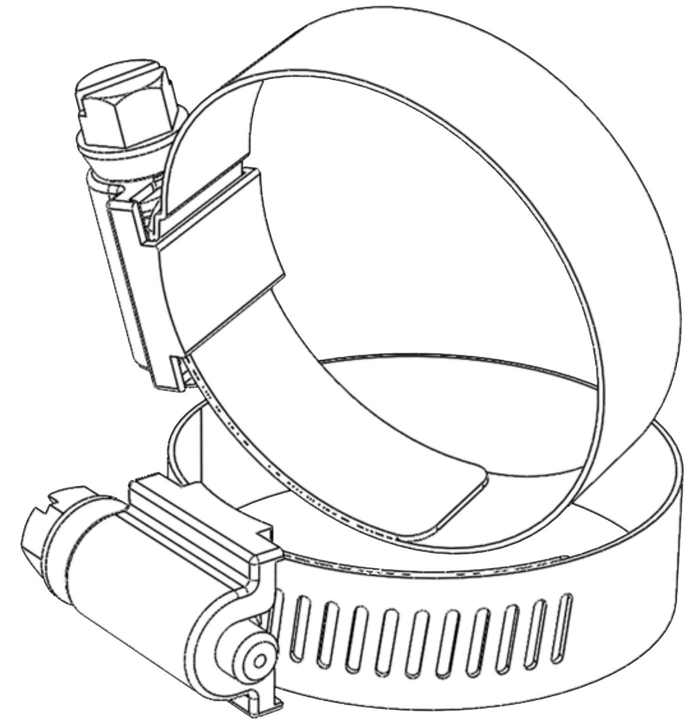


Figure: 3 Protective Inner Sleeve

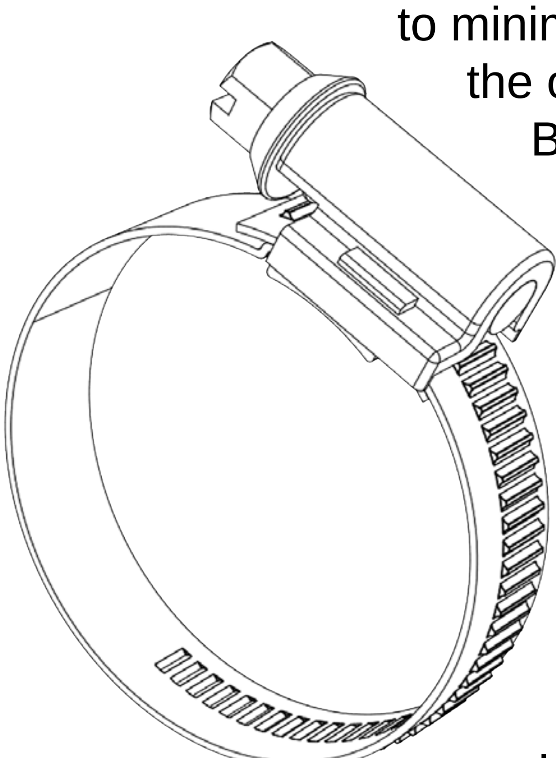


Figure: 4 Embossed Clamp

In comparison, the worm drive type clamps can typically accept a tightening torque between 10 to 30-inch pounds depending on the type and width, whereas, the bolt type band clamps can typically accept 75 to well over 100-inch pounds of torque on some types. These types of clamps also have a much more specific size range.

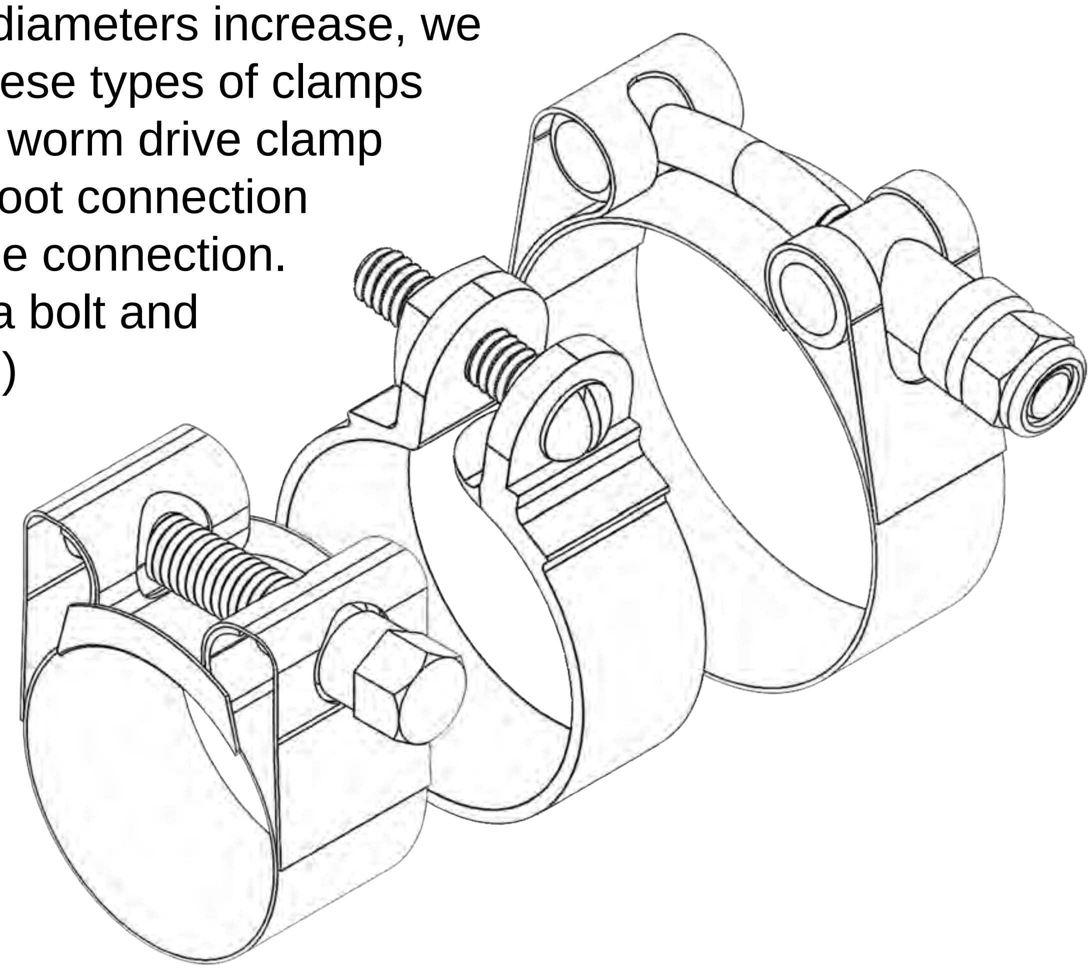


Figure: 5 Bolt Style Clamps

Often, these clamps have a range limitation requiring a different clamp for each 1/8 to 1/4 of an inch variation in hose diameter. All these band type clamps, by the very nature of their construction, have limitations as to the minimum hose diameter in which they will function properly. The drive gear box for the worm type clamps is usually square and bulky. This tends to apply uneven pressure on the hose at the edges of the gearbox housing resulting in the necessity to over tightening the clamp in order to prevent leakage.

When we talk about hoses that are 1 inch in diameter and smaller, we almost always opt for a different style of clamp. There is a whole host of what we refer to as constant tension spring clamps. (Figure: 6) You will find these types of clamps on nearly every engine manufactured, as well as throughout most airframes. The big plus with these types of clamps, is that they are constructed in such a fashion as to provide a very uniform fit around the perimeter of the hose. This makes these ideal for the smaller size hoses used in low pressure systems. These types of clamps also have a limited range, and typically, have a clamp size specifically suited for each size hose. In addition to their precise circular shape, the clamps act as a spring that provides very uniform pressure around the hose that compensates for changes in environmental conditions such as temperature, allowing the hose to expand and contract along with the given conditions. Although you can manipulate these clamps with a pair of pliers, when it comes to working in an engine compartment where access is limited, trying to keep a pair of pliers in position on the end of a clamp can be a tedious and frustrating experience. Our favorite tool that we use for installation and removal of these type of spring clamps, is a pair of Knipex spring clamp pliers.(Figure: 7) These are specifically designed to work with most types of spring clamps, and feature a set of rotating jaws that allow the pliers to be positioned at any accessible angle that you might have

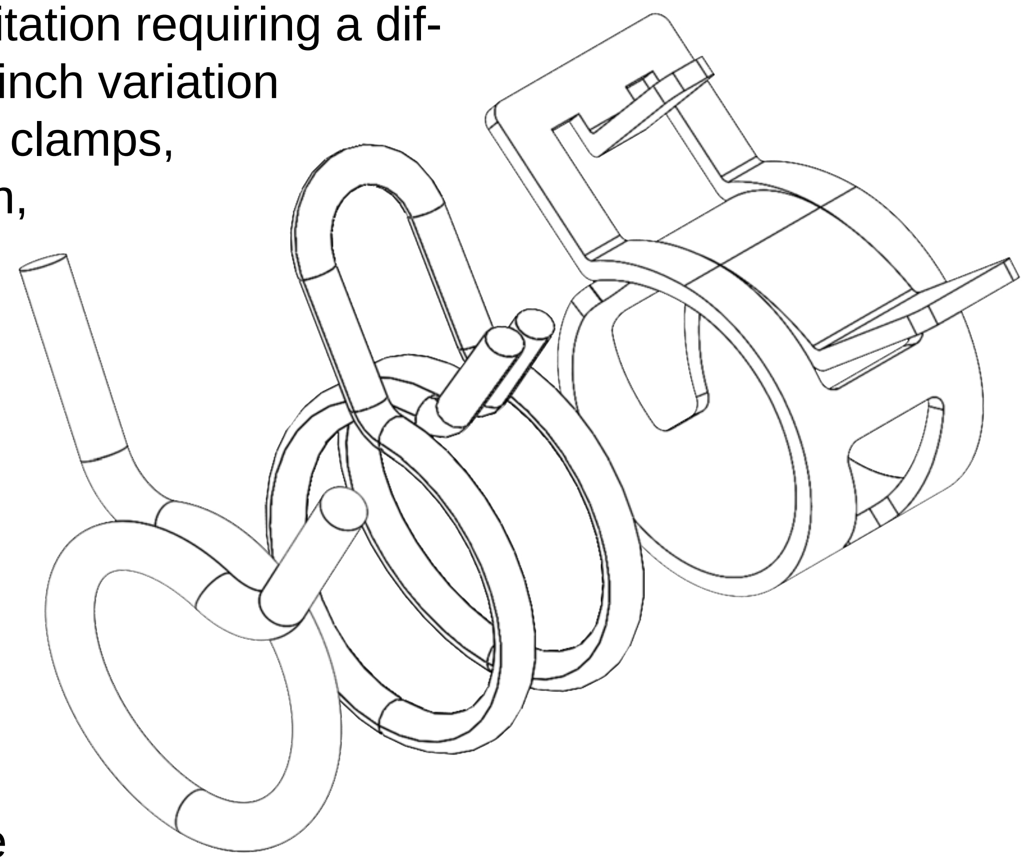


Figure: 6 Spring Clamps

Figure: 7 Knipex Hose Clamp Pliers

available. With a pair of these pliers, the spring clamp is by far the easiest and quickest of all the hose clamps when it comes to installation and removal.

When we have a hose installation that we would like to have a more durable and permanent type of attachment, we normally opt for a pinch clamp. Although there are several manufacturers of these type of clamps, you may be familiar with the most popular type, the Oetiker clamp. (Figure: 8) These clamps also come in very specific sizes and have a limited range of crimping ability. The installation of these clamps is relatively straightforward, using a pair of special crimping pliers, the crimp ends are squeezed together reducing the overall diameter of the clamp. (Figure: 9) And unlike all the other types of clamps that we have talked about so far, these clamps are a onetime use. Once clamped in place, these clamps cannot be removed without cutting the clamping band into two pieces for removal. This is also just as simple as the installation process. In fact, the crimping pliers also act as the cutters that are used to remove the clamps. These clamps come in a variety of designs, but typically are broken down into a single ear or a double ear style. These types of clamps are particularly useful on the very smallest of hose sizes. An example of this is the 1/8-inch diameter oil injection lines on the Rotax two-stroke engines. There is virtually no other clamp that will work for this application.

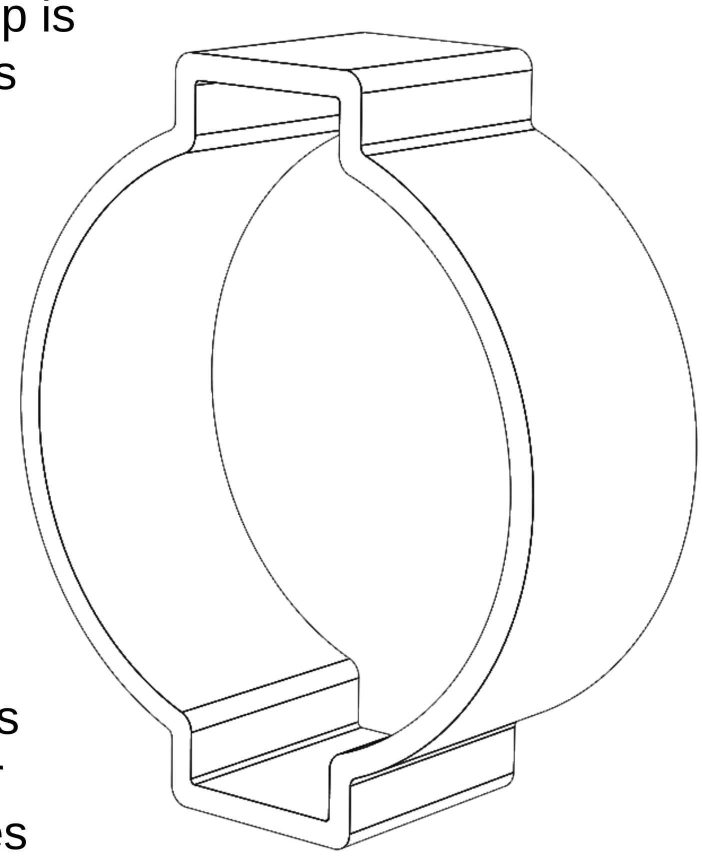


Figure: 8 Oetiker Clamp

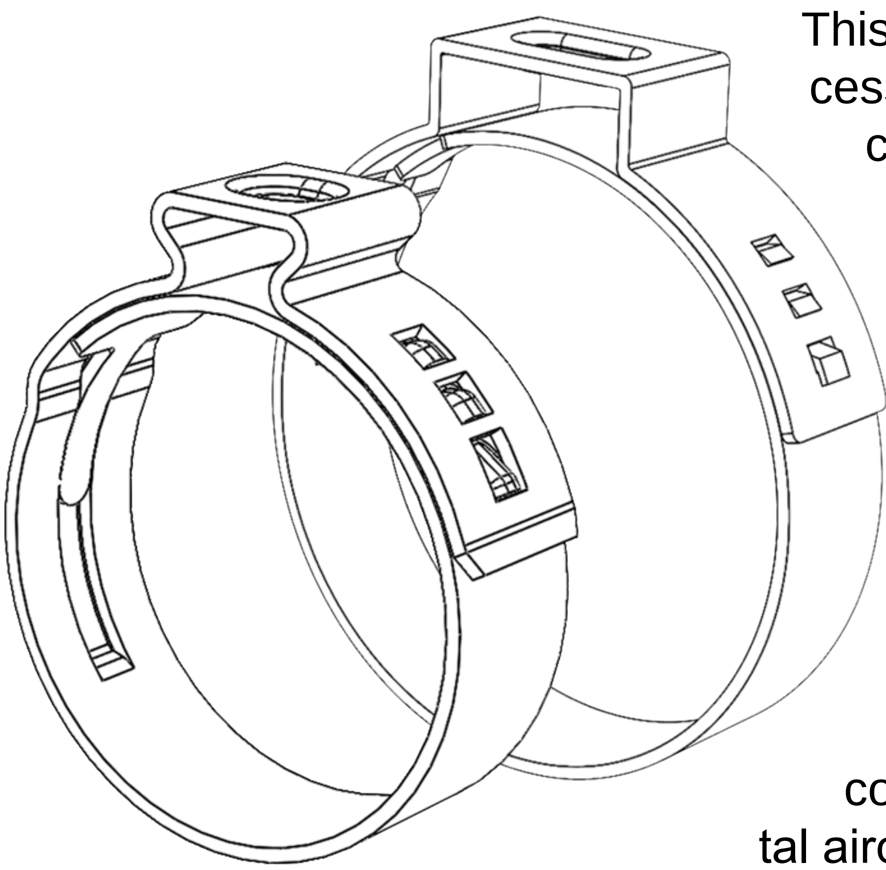


Figure: 9 Pinched and Un-pinched

In this article we have looked at the most commonly used hose clamps for experimental aircraft. There are literally hundreds of different variations on each of these designs. And as a result, there are many nuances to the proper installation and utilization of each of these different products. Following the clamp manufacturer's recommendations for utilization as well as installation procedures will keep you leak free and operating smoothly.

Like it or not drone technology is not only here to stay, we are confident that in the very near future, the infiltration of drone technology will completely revolutionize how we even think about the term “experimental aircraft.” It wasn’t many years ago, that those of us involved in the RC (radio control) model aircraft industry, started tinkering around with some of the new, electric powered, micro helicopters. With the advent of the new lithium batteries, the industry was awash with innovative new electric powered aircraft, helicopters, and then, the new introduction of the “quad copter.” This forever changed the model aviation industry. Most of us that became involved with the first iteration of drones learned to fly them through the use of simulators and lots of practice. In the early days of the quad copter, and long before electronic gyro stabilization an integrated GPS had been perfected, the skills necessary to master one of these little monsters was quite substantial. This usually involved a significant number of crashes followed by Tourette’s laden profanities. If your resolve, persistence and wallet held out, it became possible to not only become proficient, but really master these little machines. They proved to be quite agile and capable. If you grew up flying radio control aircraft, the transition was significantly easier. But for many a novice, the challenge and the cost proved to be just too much to be enjoyable. In recent years the technology on the quad copter type drones has improved to the point that a new operator, without prior experience, can become proficient in short order. In fact, the new technologies allow the aircraft to virtually fly themselves without any intervention from a pilot whatsoever. DJI (Da-Jiang Innovations) is arguably one of the most prolific manufacturers of drones. This Chinese company sells a variety of drones. Their entry-level drones cost only a few hundred dollars while there commercial drones can often run tens of thousands of dollars. We purchased The DJI Inspire 1,(Figure: 1) solely for the purpose of commercial photography and video. It is a professional grade drone with amazing capabilities and 4K gyro stabilized video quality worthy of a feature-length film. Often times, when on a photo shoot, I will grab

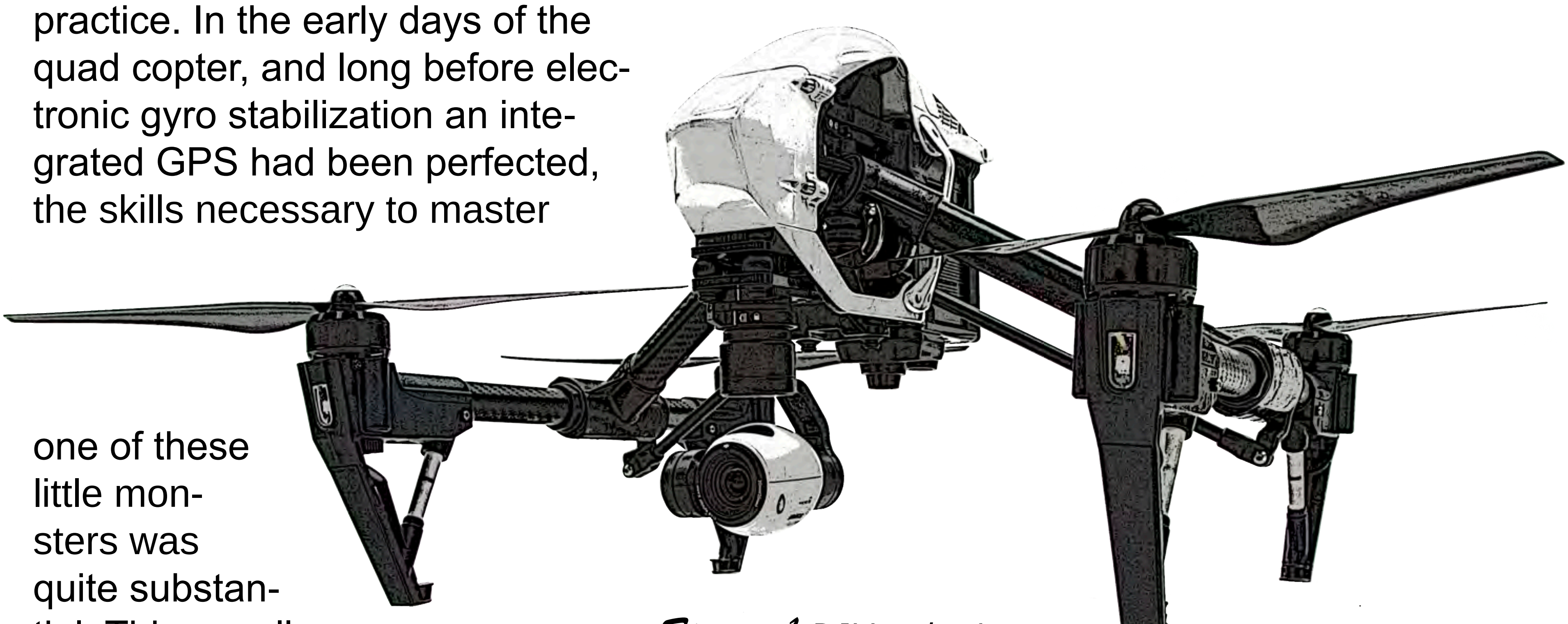


Figure: 1 DJI Inspire 1

one of the many onlookers and ask them if they want to fly it. The response is usually the same, “I don’t know how to fly a drone.” I promptly hand them the controller and say “I’ll teach you.” “Push that button that says takeoff.” “Now push that button confirming that you want to takeoff.” Magically, the motors begin to spin up. Seconds later the craft lifts off the ground and begins a climb. Simultaneously the landing gear booms retract into the flight position, and at about 5 feet off the ground the Inspire 1 settles into a hover so stable you might think the aircraft was on a tripod. “There now, that wasn’t so hard was it,” I say. “Wow,... that’s so cool” is the typical response. Automatically keeping the Inspire 1 stable and steady during flight is an advanced Inertial Measurement Unit (IMU). The IMU incorporates both a 6-axis gyroscope and an accelerometer to monitor changes in tilt and movement. In addition, a Vision Positioning System utilizing both visual data and sonar waves that detect both variations in patterns on the ground as well as altitude. If that wasn’t enough, the Inspire 1 utilizes an intelligent GLONASS + GPS system, providing pinpoint positioning of the aircraft. The Electronic Speed Controllers (ESC’s) are what control the aircraft’s every movement by providing precise power adjustments to each of the crafts four brushless electric motors. The logarithm that controls the ESC is nothing short of amazing. All of the flight parameters, like torque, that would otherwise require a veteran pilot’s expertise

Figure: 2 Dual Control Operations

are automatically taken care of. Flight transitions are smooth and accurate and the controls are very easy to manipulate. Forward and backward, as well as, left and right on the right stick. And up and down altitude control, as well as, left and right yaw control on the left stick. Pick an altitude; the aircraft will stay there until you decide to change it. This, regardless of the other inputs to the controls. Let go of the controls at any point in time, and the aircraft makes an immediate transition to hover flight and stays there until you provide additional input. Put the controller on the ground, walk away, come back 10 minutes later, the aircraft will be right where you left it. All of this amazing capability within this little package is impressive by itself, but we are just scratching the surface. The DJI Inspire 1 is primarily a camera platform. DJI offers a whole series of interchangeable cameras, including an infrared camera capable of night vision. All of these cameras operate on a gyro stabilized gimbal that provides shake free video that can only be comparable to video achieved on a tripod. Check that, better than a tripod. Because of the gyro stabilization, the video footage is superior to a camera on a tripod being manipulated by an operator. We often use the camera and gyro stabilization on the Inspire 1 as hand held video platform because of its superior stabilization capability. The Inspire 1 also has the capability of dual opera-

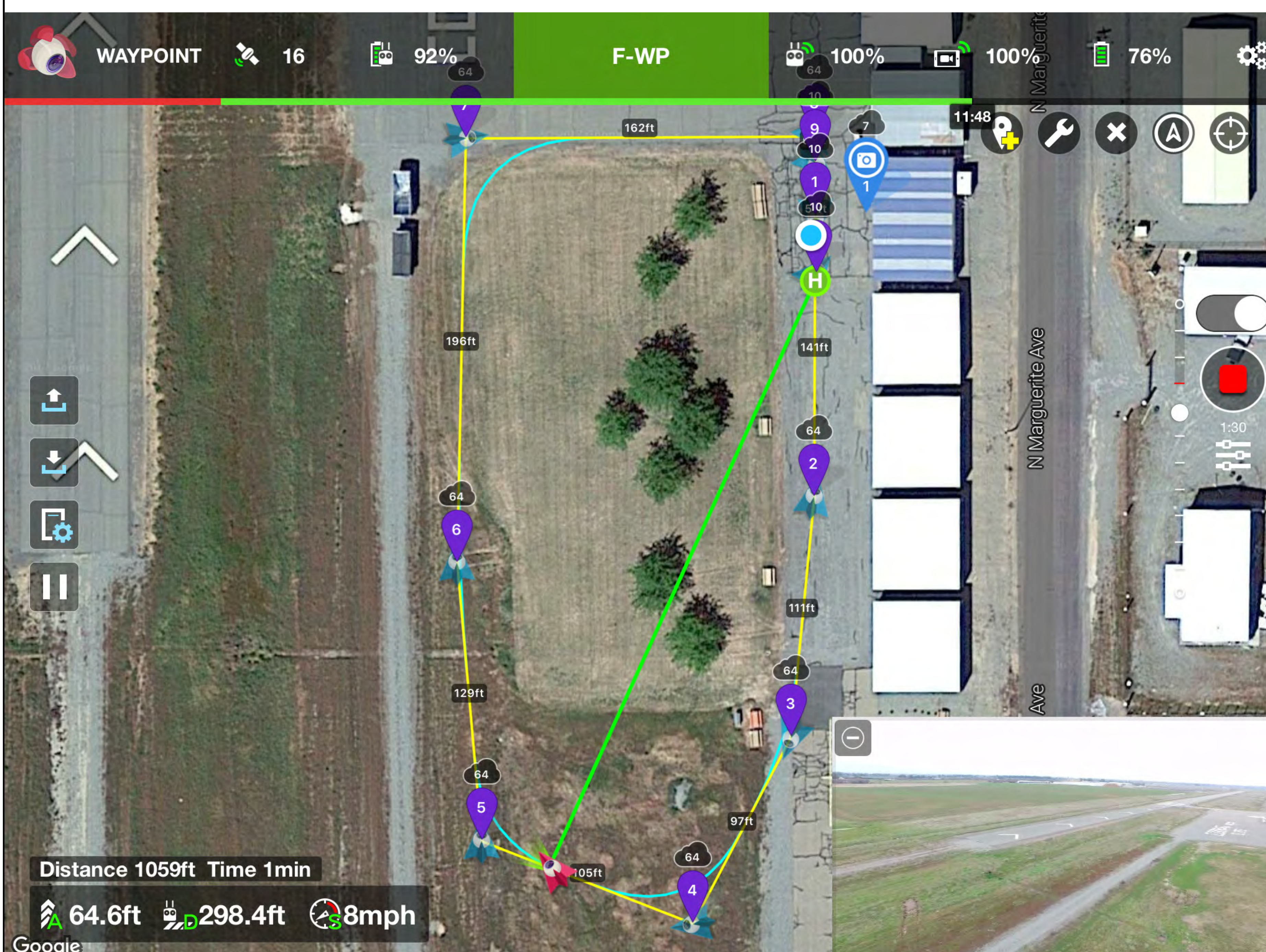


Figure: 3 Litichi App in Waypoint Mode tors. One operator flying the aircraft and the other operator controlling the camera functions. (Figure: 2) The camera operator can also manipulate the camera through FPV (first person view) goggles. During filming, the operator dawns the “virtual reality” goggles and now the camera operators head movements control the position of the camera. The quality of the video footage is now seamless and natural. But wait, there’s more. The DJI controller interfaces with an iPad (or android device) for its primary operating functions. There are several apps that allow us to interface with the Inspire 1. The DJI Go app is the default app, very powerful in itself. And then there are several third-party apps that bring the operation of the Inspire 1 to and entirely new level. The most common apps, and the ones that we use, are the Litchi, and Autopilot apps. Utilizing these apps we have a graphical interface very similar to that of a EFIS or MFD utilized in most modern aircraft. We have Google Earth map interface showing the exact location of the drone as well as a first-person view of what the camera is seeing during flight. The app contains a myriad of screens allowing us to monitor and control the operation of the aircraft as well as monitoring and warning functions for the batteries on the aircraft and the controller. In addition there are screens for controlling, and operating camera settings just as though you had a digital SLR camera in your hand. Utilizing the Litchi app (Figure: 3) or Autopilot app we can create a complete flight plan on our desktop or ipad by selecting waypoints, altitude positions, camera orientation, speed, heading, etc. We can then upload the flight plan to the iPad. And then, with a single push of a button, the Inspire 1 will fly the entire mission, waypoint to waypoint, taking video and pictures at the preprogrammed locations, then return to the home location and conduct a landing and engine shutdown, all autonomously without any outside intervention. In fact, in the event of loss of signal from the controller, or with a single push of a button by the operator, the aircraft will autonomously climb to a the designated safe altitude and then return to home and land itself. The flight plan that you create can be saved and re-downloaded to duplicate the flight again in the future. Software and firmware updates are now commonplace and easily instituted keeping the drone and controller in tip top shape as new innovations are incorporated. The industry is innovating at a frenetic pace with several thousand drone manufacturers now bringing new products to market. Only a few years ago, human caring drones were a thing of science fiction. That can no longer be said. There are many manufacturers currently working on human carrying drone technology. One of the more interesting projects is the EHANG

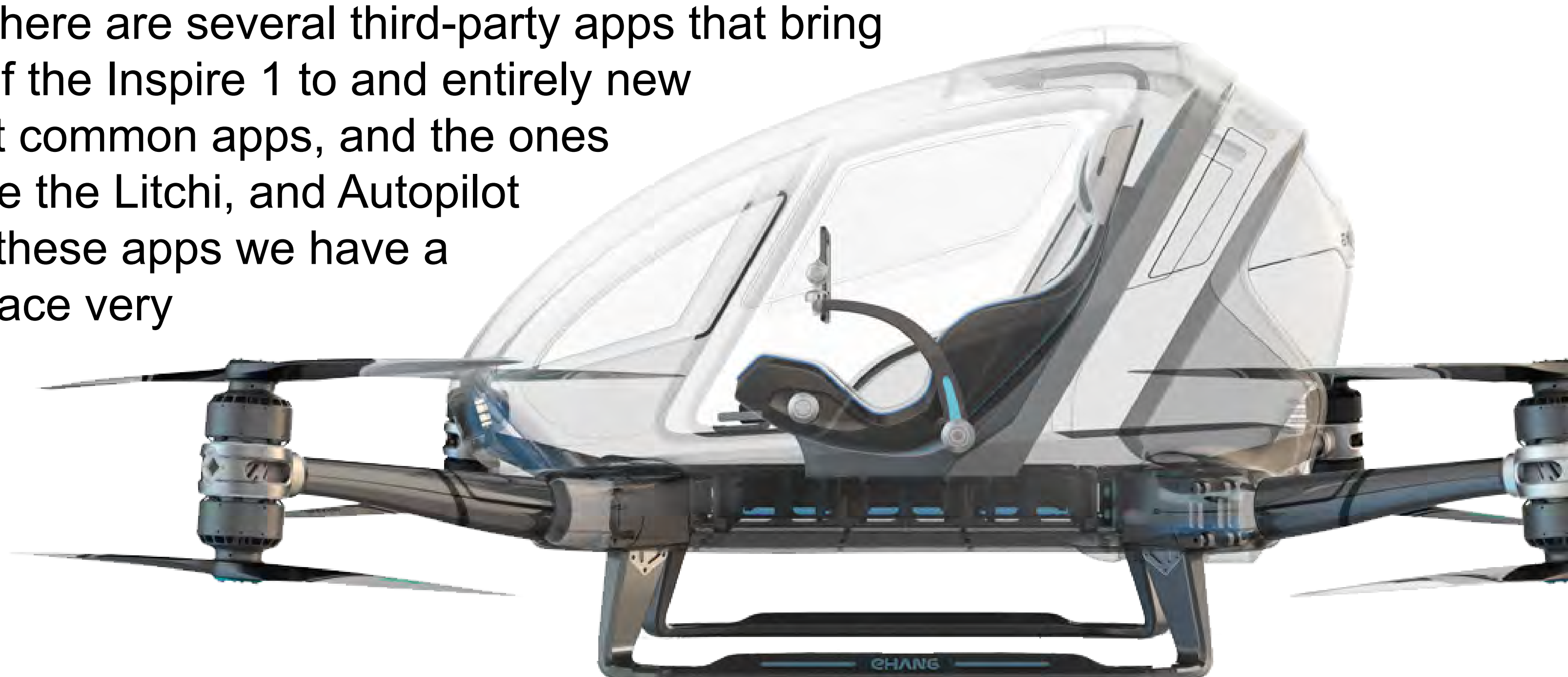


Figure: 4 EHANG 184

Figure: 5 EHANG 184 Touchscreen

184.(Figure: 4) This Chinese company cut its teeth on manufacturing drones for the hobby industry and it didn't take long for the company to see the advantages of utilizing their technology in a much more ambitious enterprise. The EHANG 184 is an 8 motor electric powered single person drone, or as they like to advertise it, an "air taxi". Their ambitious goals for the aircraft show only a glimpse of what's to come in the future. When you climb into the cockpit of this aircraft you notice an immediate disconnect from what a pilot would normally be looking at. Void of all flight controls and sporting only an instrument panel that consists of a touchscreen reminiscent of that on the DJI Inspire 1.(Figure: 5) All of the technology that flies this craft, is essentially an enhancement on the technology built out of their experience with the smaller hobby versions of their other drones. And after having experienced this same technology first hand, with all of its redundancy, dependability and reliability, we can assure you, this is the future.

Carol and Brian Carpenter are owners of Rainbow Aviation Services in Corning, California. For more Information visit www.rainbowaviation.com

Low-Budget Hydro-forming

RAINBOW Aviation Services™

We are often looking for methods for creating parts on our experimental aircraft that replicate the professionalism of factory built aircraft. The biggest stumbling block is usually the cost of set up for fancy tooling and machinery. Yet, you might be surprised by what you can accomplish in your own small workshop. In fact, many of the greatest ideas in aviation originated from small workshops like yours. Those very professional looking “stamped” aluminum parts are a great example. (Figure 1) The Hydro-forming machines that are used to manufacture these parts can cost well over $100,000.

Figure 1: Hydro-formed aluminum rib

In this article, we are going to take a look at some options for you to make your own very professional looking hydro-formed parts using equipment that you probably already have in your shop. We have, for many years now, been utilizing a simple tool that we built in our shop for making small hydro-formed parts. Well..., not really hydro-formed, but rather, parts that could have been hydro-formed. By definition hydro-forming is a process using high-pressure fluid to force a malleable metal over the top of a metal die resulting in a formed metal component. Rather than using a fluid to deform the aluminum parts, we are going to be using a block of rubber contained within a steel box, pressed over the top of a die to form our metal components. And to provide the pressure necessary to cause the rubber to flow like a liquid, we are going to use a 20 ton the Harbor Freight hydraulic press.(Figure 2)

Making the box: (Figure 3) This is where many people get a little overambitious. The amount of pressure necessary to cause the rubber to flow like a liquid is quite substantial. Let’s do the math. Our box is 11” x 11” inside dimension. That is approximately 120 $in.^2$ The force available on our press is 40,000 pounds. 40,000 ÷ 120 = 333 PSI (pounds per square inch). That is about the minimum force necessary for conducting this hydro-forming process. Normally, the parts do not consume the entire area of the box and thus the amount of initial force over the die is greater. As the parts get bigger, the amount of forming force gets distributed. Some manufacturers are creating ribs and using the hydro-forming process without completely bending the flanges on the rib. Even if

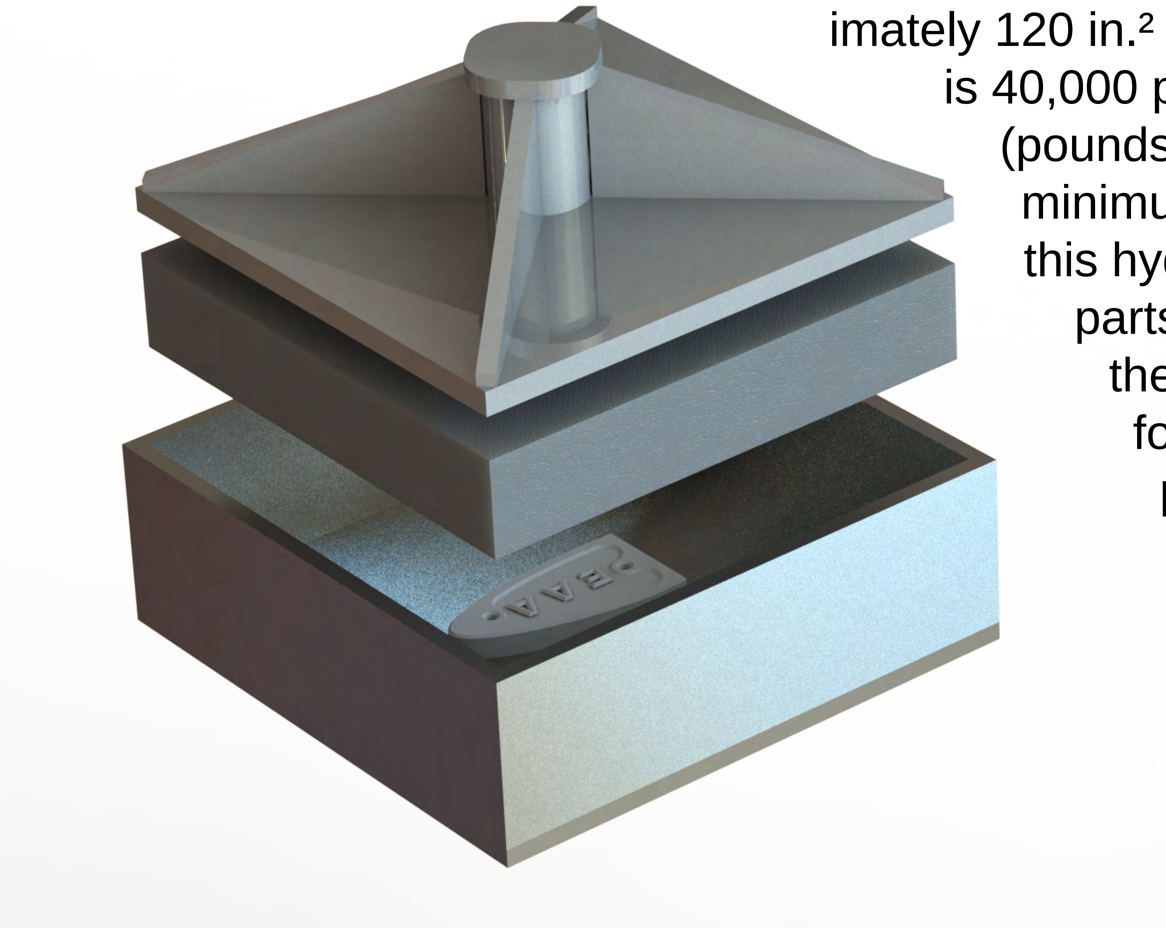


Figure 3: *Hydro-forming box*

the total force available is not sufficient to bend the flanges 90°, you can still use the hyrdo-forming pressure to initiate the bend of the rib flange. Even if the flange is only bent to 30°, it provides a initial shape that allows us to finish the flanges on the rib using a hand bending tool and a metal shrinking tool or a pair of fluting pliers to finish shaping the flange. This is actually a preferred method when you're working flanges onto a part with a smaller radii.

The most common question is always, "What type of rubber should I be using?" And, of course, the answer is "it depends." The harder the Durometer of rubber, the more definition you will achieve in your final product. However, it becomes harder for the rubber to flow resulting in higher required pressures. A good starting place would be a durometer of Shore 40A to Shore 60A. To give you an idea of the relationship to that hardness, Shore 20A would be similar to a rubber band and Shore 60A would be about as hard as a car tire tread. Normally, the highest cost of making your own forming machine is the cost of the rubber. Because of this, you may want to see if you can find a sur-

Figure 2: *Harbor Freight press*

plus piece of rubber big enough to manufacture your part before you begin manufacturing your box. Then build your forming box to fit your piece of rubber. Keep in mind that even if you can't find a 2 inch piece of rubber, several pieces of a lesser thickness will also suffice. Our 2 inch block, which we are using, is actually 2 pieces of 1 inch thick neoprene rubber glued together.

Making the dies: (Figure 4) There are many ways to manufacture dies which we can use in forming aluminum. Even the use of MDF (Medium Density Fiberboard- that you can buy at Home Depot) will work very well. The downside is that MDF won't last as long as other materials and cannot withstand higher pressures. However, if you're just going to make a dozen simple parts, MDF may be more than adequate for the task. Of course, steel and aluminum will work very well. They hold up well and last for as many parts as you want to make. The downside for these materials is that it may require specialized equipment for the machining of the die depending on its complexity. Our favorite material for manufacturing dies is Corian. Corian is an acrylic polymer that is commonly used in the manufacturing of kitchen countertops. The Corian material is very easy to machine and manipulate with both machine and hand tools. It can be cut with a table saw or a bandsaw. It can be sanded, filed, and drilled very easily. It is also very durable. We have used Corian for parts where we have a need to form up to, or more than, 100 pieces. Although, Corian is very expensive if you are purchasing it outright, we find that we can purchase scrap Corian material from counter top companies for pennies on the dollar. Every countertop sink cutout is simply scrap material, and ironically, it is also about the largest size piece that we can use in making a die for our small forming machine.

Figure 4: *Aluminum dies for hydro-forming*

The Forming Process: There are quite a few tricks that will bridge the gap between frustration and success. To start with, knowing your material is very important. Because of the high tensile strength of 2024 T-3 aluminum forming this material can be quite tricky. Keep in mind that during the forming process, the material will have to stretch and compress depending on the shape of the die. Compound curves become more difficult than simple bends and sometimes adding special features into the die to absorb the tension or compression within the metal will make the forming process more successful. Using an aluminum that is annealed like 2024 O is much easier to form, but will require heat treatment after the forming process in order to retain the strength properties of the tempered aluminum. Although not as strong as 2024 T-3, 6061 T-6 aluminum can compress and stretch around a die a little bit better when you're trying to get a bit more aggressive with your forming process. When you get very aggressive with the shape of the die your relegated to forming with an annealed material and heat treating after the final product. (Figure 5) shows an example of 2024 T-3 aluminum being aggressively formed at about 2000 PSI, stretching the aluminum to the point of cracking.

Another trick, that we find very useful, is using Lemon Pledge as a lubricant. If the parts and the rubber are dry during the forming process, the rubber will grab the metal and force extra stress into the aluminum when the rubber is pressed over the die. By using a lubricant, the rubber will slide and move easily preventing the pulling and tugging on the aluminum.

The next trick we find helpful is utilizing sacrificial rubber in addition to our rubber forming block. We use old innertubes cut into small squares that will fit inside of the forming box to act as a buffer against the sharp edges of the forming block. Rather than tearing at the expensive piece of solid rubber, we can improve its longevity by sacrificing individual pieces of scrap innertube. The innertube material is also of a lower durometer which can help in the forming process where a more fluid rubber is needed to form around large flanges. We have experimented and found that even using multiple layers of innertube material will work in place of our large 2 inch rubber block. This, however, is a bit cumbersome and unpredictable.

The process off hydro-forming with this system is quite simple. (Figure 6) Make up the die that you wish to form the shape of the material to. Precut your metal to provide the maximum ease and forming. Create some positioning pins to hold your sheet-metal to the form block. Place your part into the center of the box. Spray the part

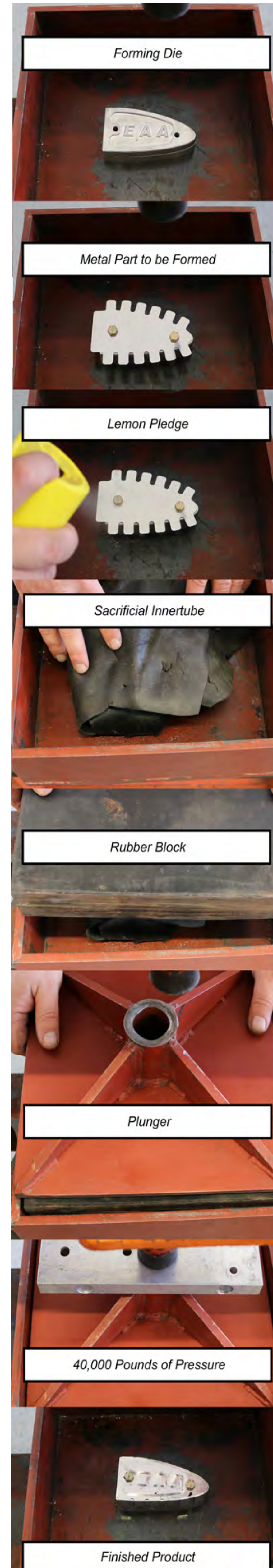


Figure 5: The Hydro-forming process

with a lubricant (Lemon Pledge). Place some sacrificial rubber evenly over the top of the part to be formed. Place your 2 inch rubber block on top of the sacrificial rubber. Place the plunger over the rubber block. Using the hydraulic press, force the plunger onto the rubber block to form the sheet-metal to the shape of your die. Remove the plunger, the rubber block, and the sacrificial rubber to reveal your completed part.

This process is not without its difficulties. The development of a die used in the process of forming metal is at the very least an art. Learning how to mold the die in such a way that you don't end up with cracks or wrinkles takes a lot of trial and error. On simple parts the learning process can be rather painless. However, on very complex large parts with thick metal, things get trickier. Developing ribs without the cutaways for the flanges are easily accomplished by using fluting pliers on the flanges, positioning the flutes before the forming processes started. Building cut outs into the die can allow the excess metal to be taken up without wrinkling. With a little trial and error, you will soon learn what you can get away with and what you can't.

Figure 6: *Cracking from over stressing the aluminum*

Once you have built yourself one of these little hydro-forming boxes, you will start to come up with all kinds of ideas on how to use it. Even though you may have other ways of accomplishing this same type of task, this process really begins to shine when you need to make multiple parts that are identical to each other. You can get your aircraft factory started today by downloading a complete set of plans for this hydro-forming box, available on the EAA website.

Click here for Link to YouTube Video on Hydro-forming

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Pipe threads are used in virtually every aircraft built today, from ultralights to Boeing's finest. In sport aviation we use the pipe thread fittings throughout the aircraft. Including Fuel systems, brakes, oil, hydraulic, coolant and even pitot static systems. The pipe fitting has been around for quite some time, however after looking through the FAA's extensive selection of maintenance publications this seams to be an area that was only touched on lightly. We continue to see confusion, problems, and even accidents as a result of misunderstanding the subject of pipe fittings.

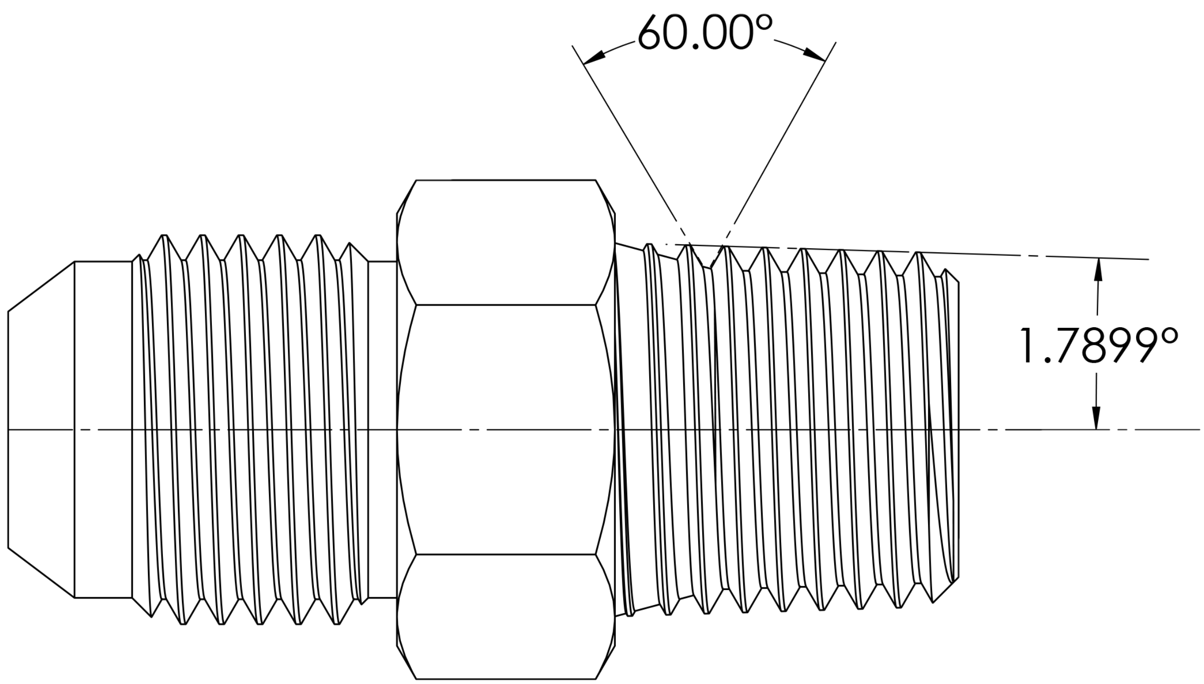

Figure: 1 *NPT (National Pipe Tapered Thread) Design*

Pipe Thread Types

The most common types of tapered pipe thread used in the United States are the NPT (National Pipe Tapered Thread), The ANPT (Aeronautical National Pipe Tapered Thread), And the

NPTF (National Pipe Tapered Fine Thread)

The NPT (National Pipe Tapered Thread) are constructed using a “Sellers” thread (truncated peaks and valleys) with threads having an included angle of 60° and a 1.7899° taper. (*Figure: 1*)

The ANPT (Aeronautical National Pipe Tapered Thread) is essentially an NPT thread that undergoes additional quality assurance requirements.

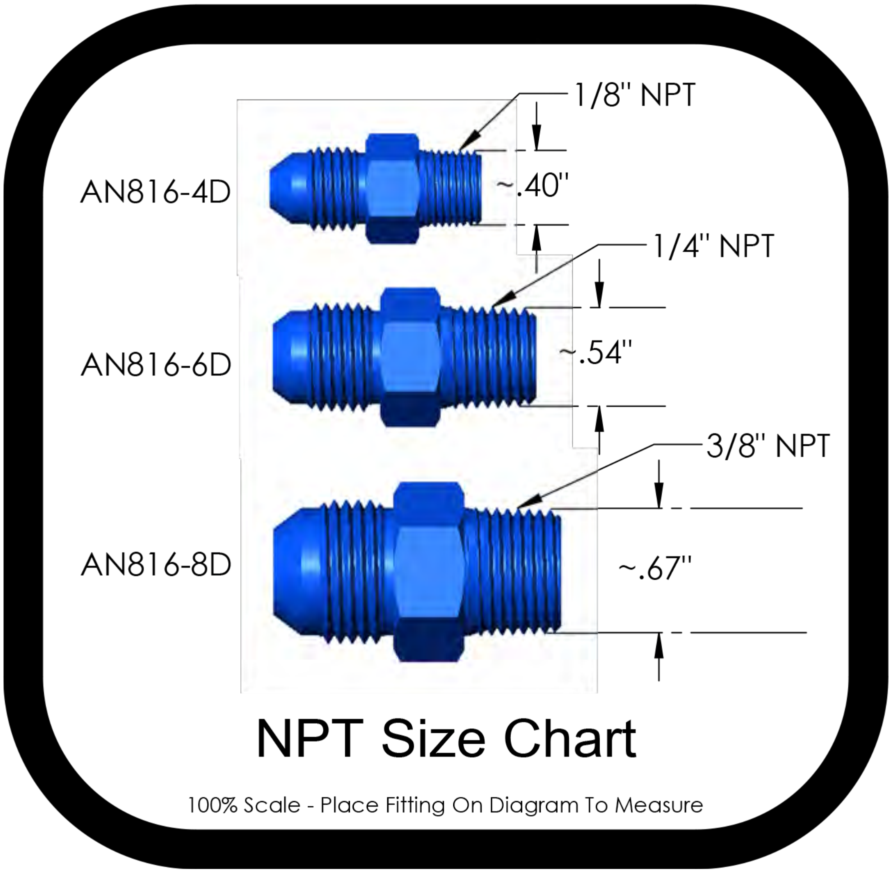

Figure: 2 NPT (National Pipe Tapered Thread) Size Chart. Place fitting on Diagram or measure pipe fitting end.

The NPTF (National Pipe Tapered Fine Thread) is also referred to as Dryseal American National Standard Tapered Pipe Thread. (ANSI B1.20.3) This thread was designed to provide a leak free seal without the use of Teflon tape or sealing compound. It is essentially the same thread as the NPT with the root and crest of the threads modified to provide an interference fit during installation. Time has shown that this often works okay during the initial installation but the use of fittings with the NPTF thread on subsequent removal and

Figure: 3 AN Fittings Color Code

re-installation will almost certainly leak without the use of a thread sealant.

Pipe Thread Size

> *"It is not possible to stop a leak on a pipe thread by tightening the fitting"*

An experienced aircraft builder or mechanic can very easily identify the size of a pipe fitting visually from across the workbench. With the limited sizes that we use in small aircraft

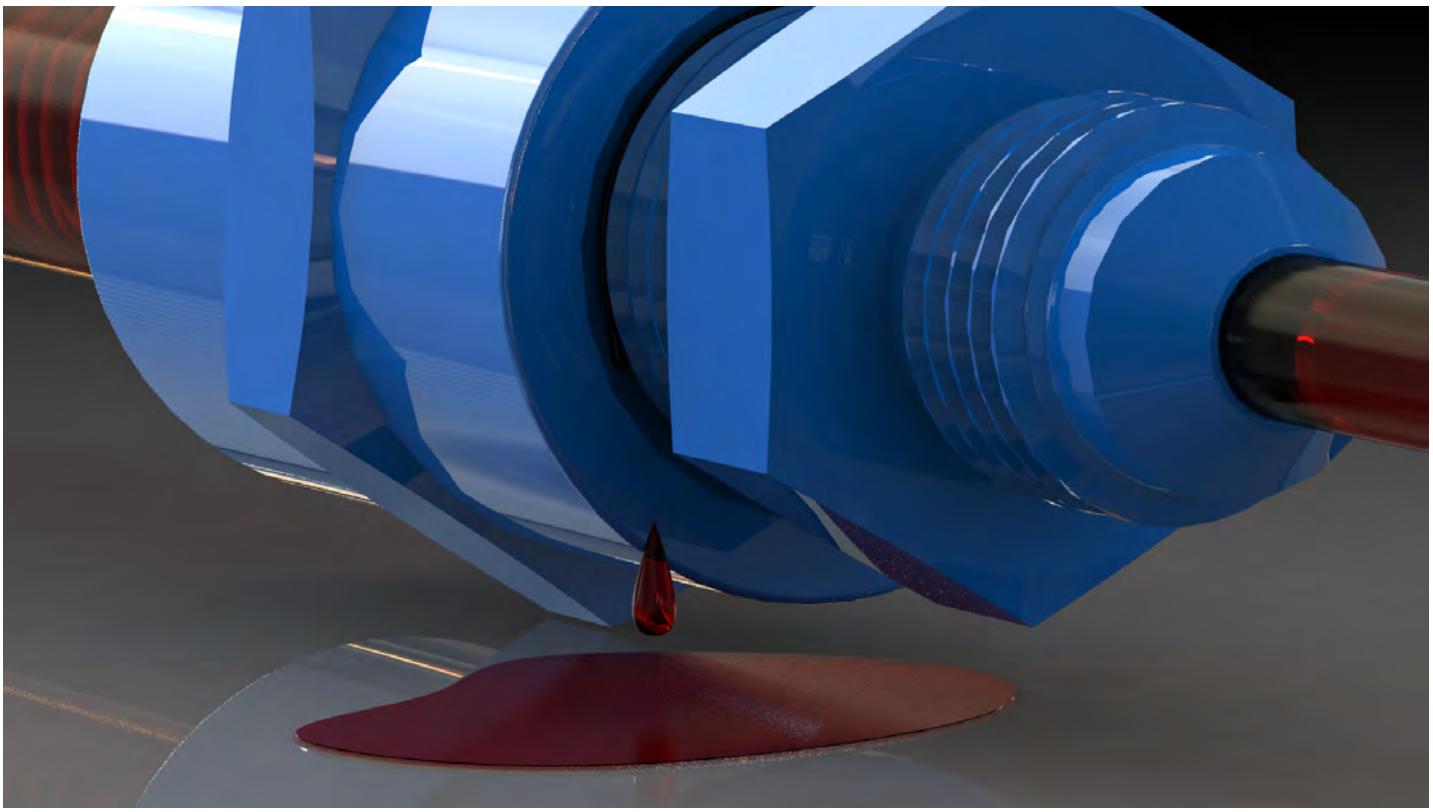

Figure: 4 *Leaking Pipe Fittings (An Aviation Hazard)*

and a little bit of practice you will soon be able to identify them by sight as well. The most common sizes used in light aircraft are 1/8", 1/4", and 3/8". Until you become familiar with the different sizes you can use the size chart (*Figure: 2*) to help with identification. Either place the physical fitting directly onto the diagram or take a measurement of the end of the pipe fitting with a pair of calipers.

Material

For easy identification aircraft aluminum fittings are anodized blue. And steel fittings are plated black. Commercial grade

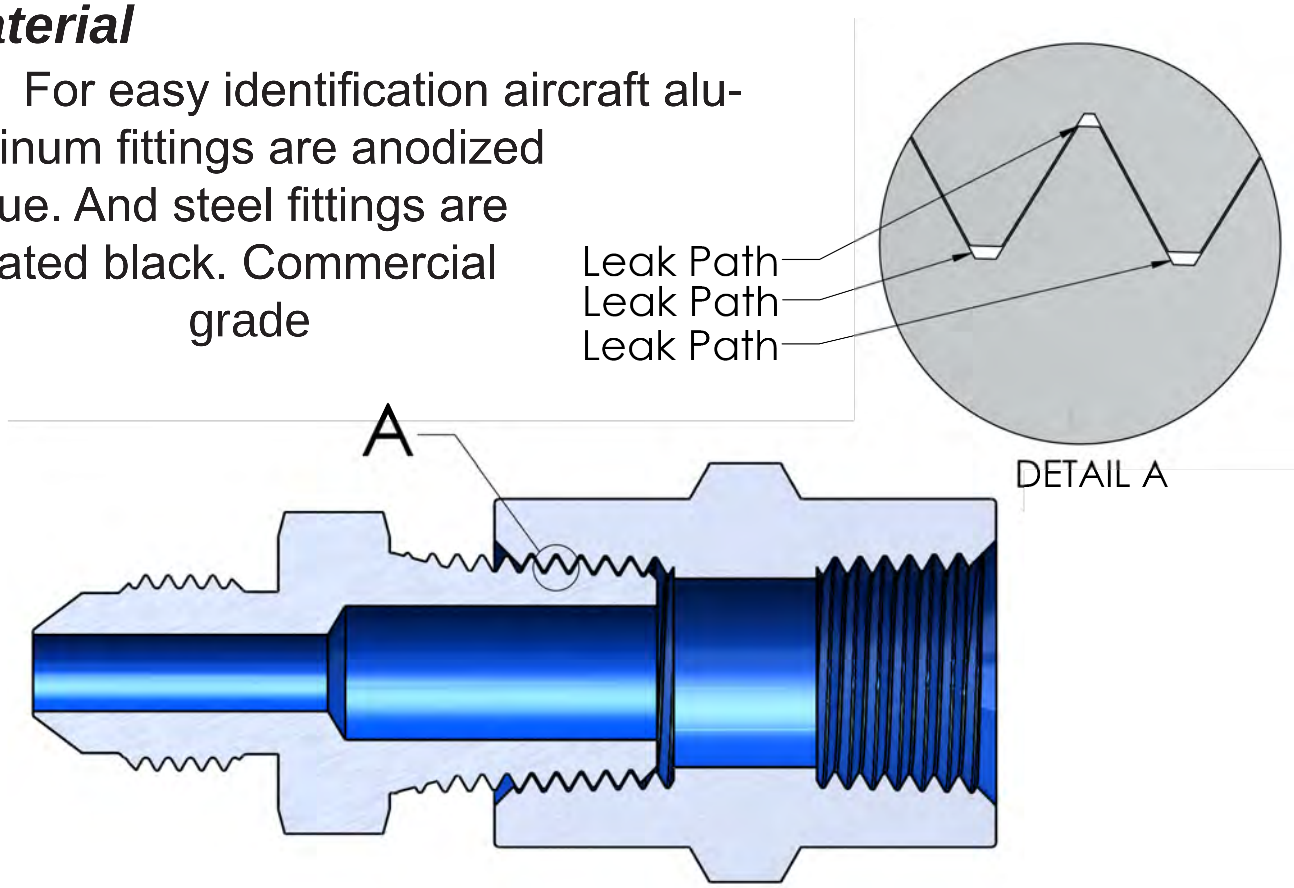

Figure: 5 *The NPT (National Pipe Tapered Thread) is constructed using a "Sellers" thread (truncated peaks and valleys)*

Brass fitting are of course brass colored.(*Figure: 3*)

Leaking Fittings

The problem of leakage arises as a result of the design of the threads. Particularly on an NPT thread where the root and the crest are truncated. (*Figure: 5*)This design allows for a helical passage from the inside of the fitting through the root and the crest of each thread to allow fluid to pass around the perimeter of the thread until it can escape presenting itself as a leak.(*Figure: 6*)

The purpose of thread sealant is to fill in this passage way between the crest of the male and female thread. It is not possible to stop a leak on a pipe thread by tightening the fitting. This is because tightening the fitting does not eliminate this passage way. If you find that you have a pipe fitting that is leaking, the only method by which you can eliminate the leak is to remove the fitting, reapply thread sealing compound, and reinstall and tightened properly.

Tips for proper installation of fittings with the NPT (National Pipe Tapered Thread)

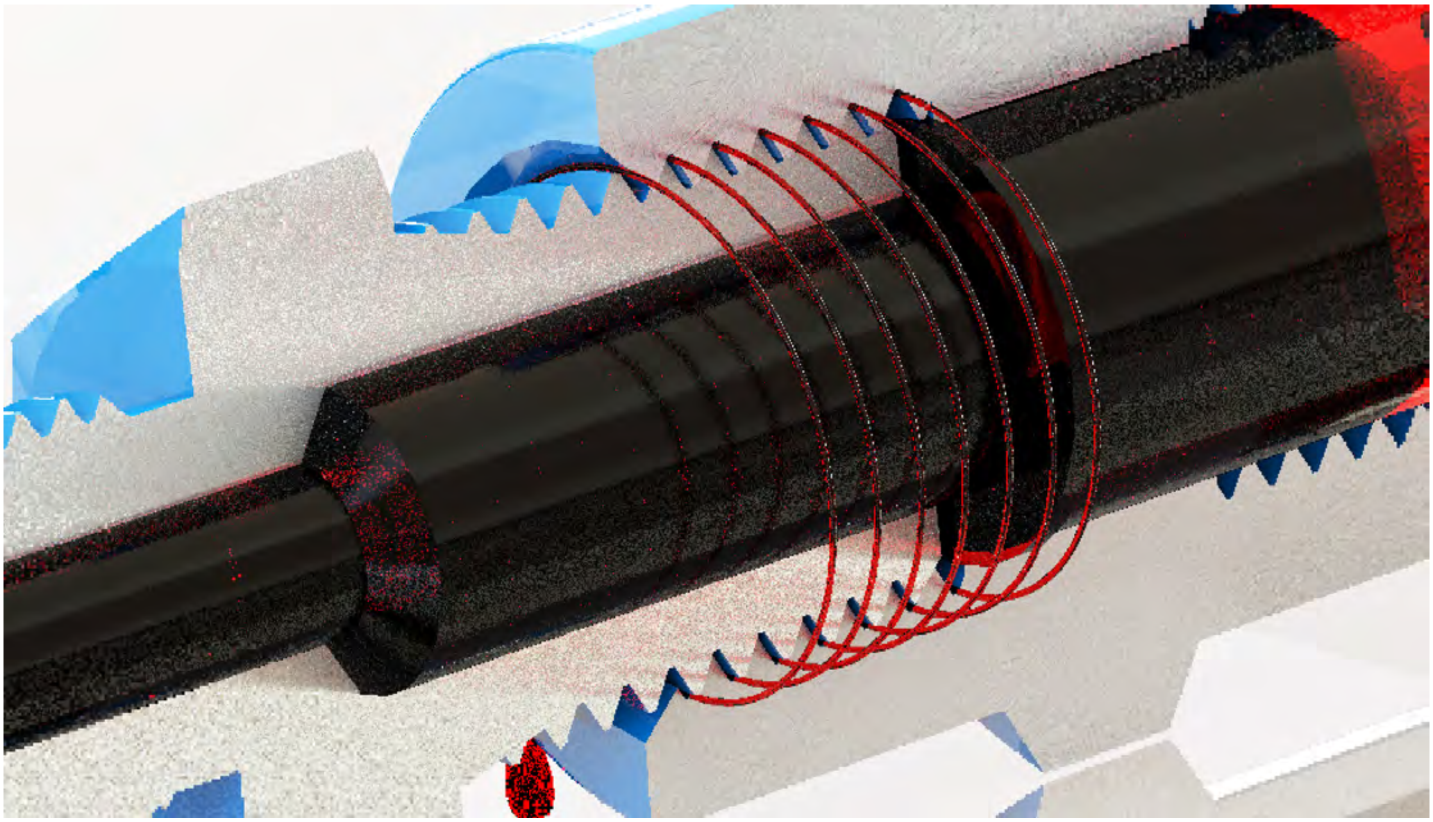

Figure: 6 With an NPT thread there is an opportunity for fluid to leak exists along a helical path at the Peaks and valleys of the threads..

Tip 1. Before installation clean and inspect both the fitting and the boss that the fitting is to be inserted into for damage and cleanliness.

Tip 2. Apply the proper thread sealant to the threads of the fitting to be installed. The type of thread sealant that will be used will primarily depend on the type of fluid used in that system. Each manufacture of a system component may also decide the

Figure: 7 Brake caliper body cracked as a result of over tightening the pipe fitting.

proper thread sealant to be used considering other factors other than the type of fluid such as temperature environment, vibration, and whether the part is removed for service routinely.

The amount of thread sealant needed is limited to the amount that will fill the void where the threads are truncated on the fitting. Ensure that no thread sealant extends to the end of the threads where it could be ingested into the fluid system. Many an engine has quit because of thread sealant or Teflon tape being ingested into a carburetor or fuel injection system plugging a fuel passage.

About the use of Teflon tape. Although there are some instances where the manufacturer recommends the use of Teflon tape on

Figure: 8 Close-up showing a crack emanating from the pipe fitting.

a pipe fitting, this is an area to tread carefully. The potential of Teflon tape being ingested into a fluid system is a high enough risk that most manufactures recommend the use of a pipe sealant instead. In addition the use of Teflon tape substantially reduces the amount of friction during installation. This can lead to over torque of the fitting and cracking of the boss in which it is installed. And because of the low friction of the Teflon tape, this also leads to loosening of the fitting in high vibration environments.

Tip 3. Install the fitting ensuring that it remains concentric to the hole in the boss during the installation process. Pipe threads are notoriously easy to cross thread. The fitting should rotate 2 - 3 turns smoothly by hand until finger tight. Less than 2 or more than 3 1/2 turns would be an indication that there is a possible problem.

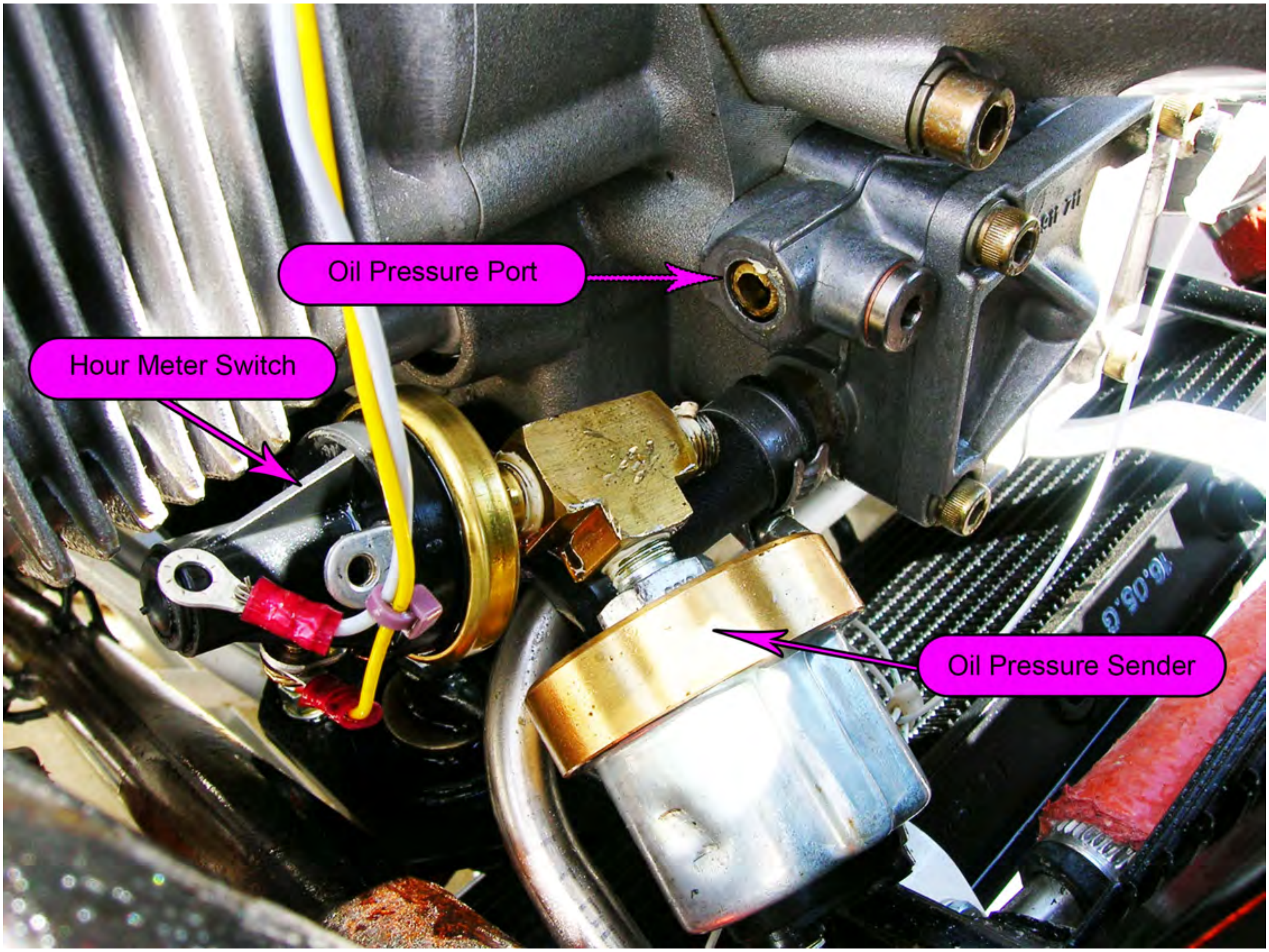

Figure: 9 Broken pipe nipple on the oil pressure outlet of a Rotax 912

Tip 4. Once installed finger tight, continue to tighten using a wrench. For the smaller size fittings 3/4" and smaller tighten between 2 - 3 turns beyond finger tight. Because of the nature of the tapered pipe thread the tightening procedure is somewhat discretionary. Although torque guidelines can be found in some publications the proper installation requires that you develop "feel" for the proper torque. A good rule of thumb would be to turn until the fitting is tight enough to prevent movement or loosening and then slightly more if needed for proper fitting alignment. Not tightening enough could result in the fitting becoming loose and leaking. Whereas over torquing could result in cracking the boss that the fitting threads into (*Figure: 7*) (*Figure: 8*).

This is particularly common when over torquing, where there is a thin cross-section at the boss and where the material is manufactured from aluminum or magnesium. The quality of the threads both internal and external very greatly and will have some effect on the amount of tightening necessary. After final installation you should have between 3 1/2 and 6 threads fully engaged.

Figure: 10 Damaged Tecnam Echo after forced landing.

Tip 5. Ensure that there are no side loads or bending loads applied to pipe fittings. There are literally hundreds of examples of system failures and airplane crashes as a result of improperly side-loading a pipe fitting.

A classic example of improper use of threaded pipe fittings. In this case here a Rotax 912 S powered Tecnam light sport aircraft was modified to accommodate the installation of a Hobbs meter pressure switch (*Figure: 9*). The original oil pressure sender was removed from the oil pressure port on the side of the engine. A commercial grade brass tee fitting was installed with a 1/8 inch brass pipe nipple into the oil pressure port and the oil pressure sender and the Hobbs meter pressure switch were installed into the tee fitting. The added weight and the extended arm of these 2 components resulted in overloading and subsequent failure of the brass pipe nipple. The end result was a loss of oil pressure and an off field landing resulting in substantial damage to the aircraft (*Figure: 10*).

Now that we understand a little bit more about the use of pipe fittings in aircraft we should be able to approach the pipe fitting from a little different perspective. We have provided some generic information and rules which should help you in making better choices regarding the use of pipe fittings. However this should never take precedence over the manufactures recommendations for your particular aircraft.

For additional information about the use of pipe fittings in aviation applications we recommend the following references:

Mechanics Tool Box (John Schwarner)

FAA-H-8083-30 Aviation Maintenance Technician Handbook General

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The Making of an Sport Aviation Article

RAINBOW Aviation Services™

EAA has made it possible for all members to have access to a free copy of SolidWorks 3D modeling software. In this article, we thought we might give you a taste of SolidWorks software capability as well as what it takes to put together and create an article and graphics worthy of Sport Aviation Magazine. It was back in January 2017 when we wrote the first article on the Bing 64 CV (constant velocity) carburetor. These articles turned out to be wildly popular with the light sport aircraft owners that utilized this carburetor on their aircraft. Ever since, we have been inundated with requests to do the same type of articles for the Bing 54 carburetors (Figure: 1) that are utilized by the vast majority of ultralight and light sport aircraft that operate the two-stroke engines. So, for the last four months we have been in the process of 3D modeling the Bing 54 carburetor. The value in the articles has always been the ability to convey a complete understanding of the carburetor's operation from both a theoretical and practical aspect. In order to have these discussions it is necessary to have diagrams, renderings, and cutaways, showing, not only the carburetor as a whole, but the internal workings, and pas-

Figure: 1 3D Modeled Rendering of the Bing 54 Carburetor sageways of the carburetor. The Bing manuals have great textual description of the carburetor's operation, but they have only basic and rudimentary diagrams of the carburetor's inner workings. Since most mechanically oriented individuals are visual learners, the lack of these specific diagrams leaves most individuals scratching their heads when trying to visualize the internal makeup of the carburetor. In our very fast-paced maintenance classes, the ability to convey practical and theoretical information efficiently is a direct result of having these detailed visual diagrams of the internal workings of not only the carburetor, but any component we are discussing. In the case of the Bing carburetors, those visual diagrams are not available. As a result, it required that we reverse engineer and 3D model each and every component of the carburetor subassembly in order to create the visual aids necessary for the classroom environment as well as the Sport Aviation Articles. And although, this carburetor was not as big of a job as the 3D modeling of the Bing 64 CV carburetor,(Figure: 2) the Bing 54 reverse engineering and 3D modeling required well over 200 man-hours to create the basic carburetor subassembly necessary to begin the process of creating renderings.

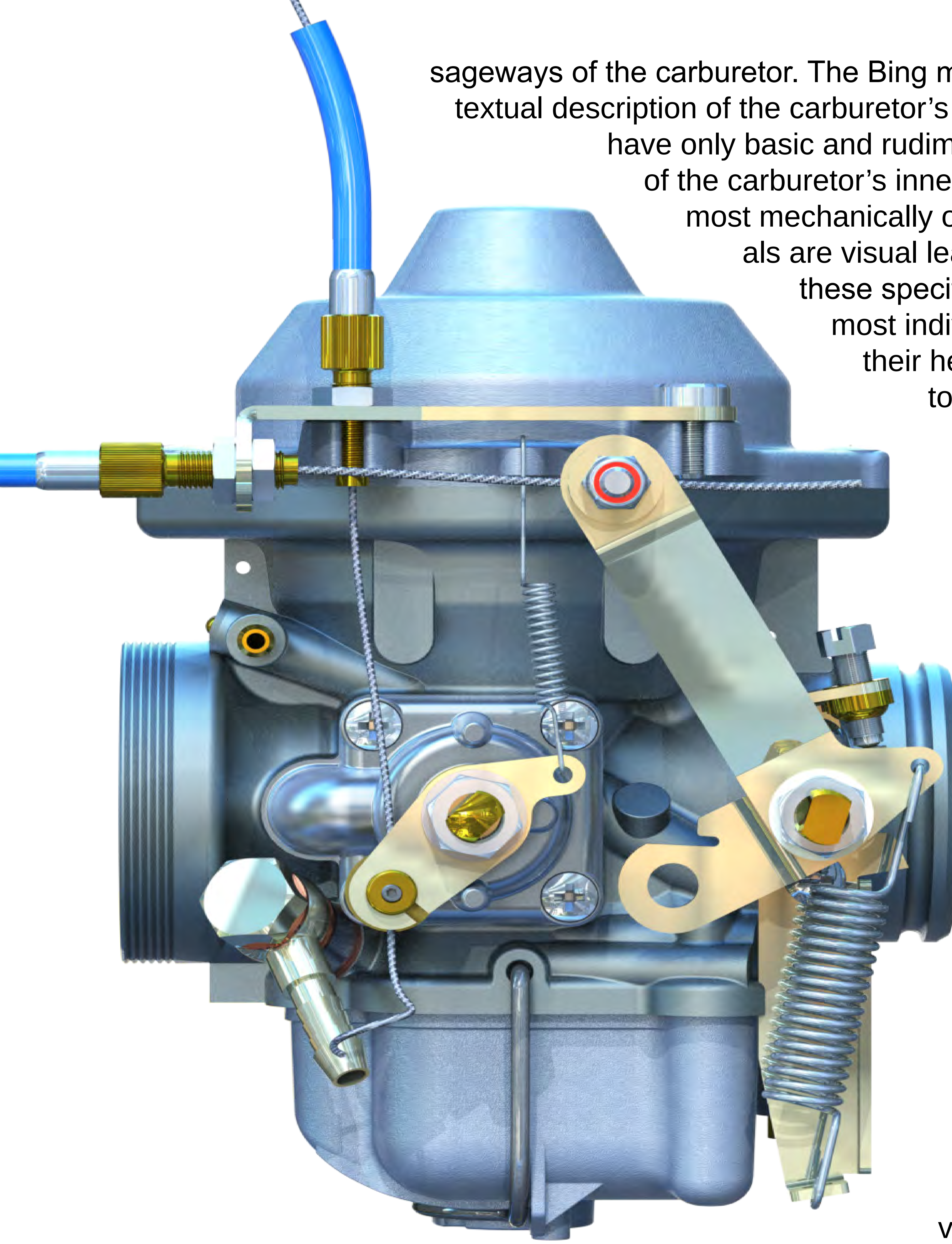


Figure: 2 Bing 64 CV Carburetor

The process begins by complete disassembly of the carburetor, then, each one of its components is measured with micrometers and calipers and modeled in Solidworks. We try and keep tolerances of .001" throughout our 3D modeling exercise,

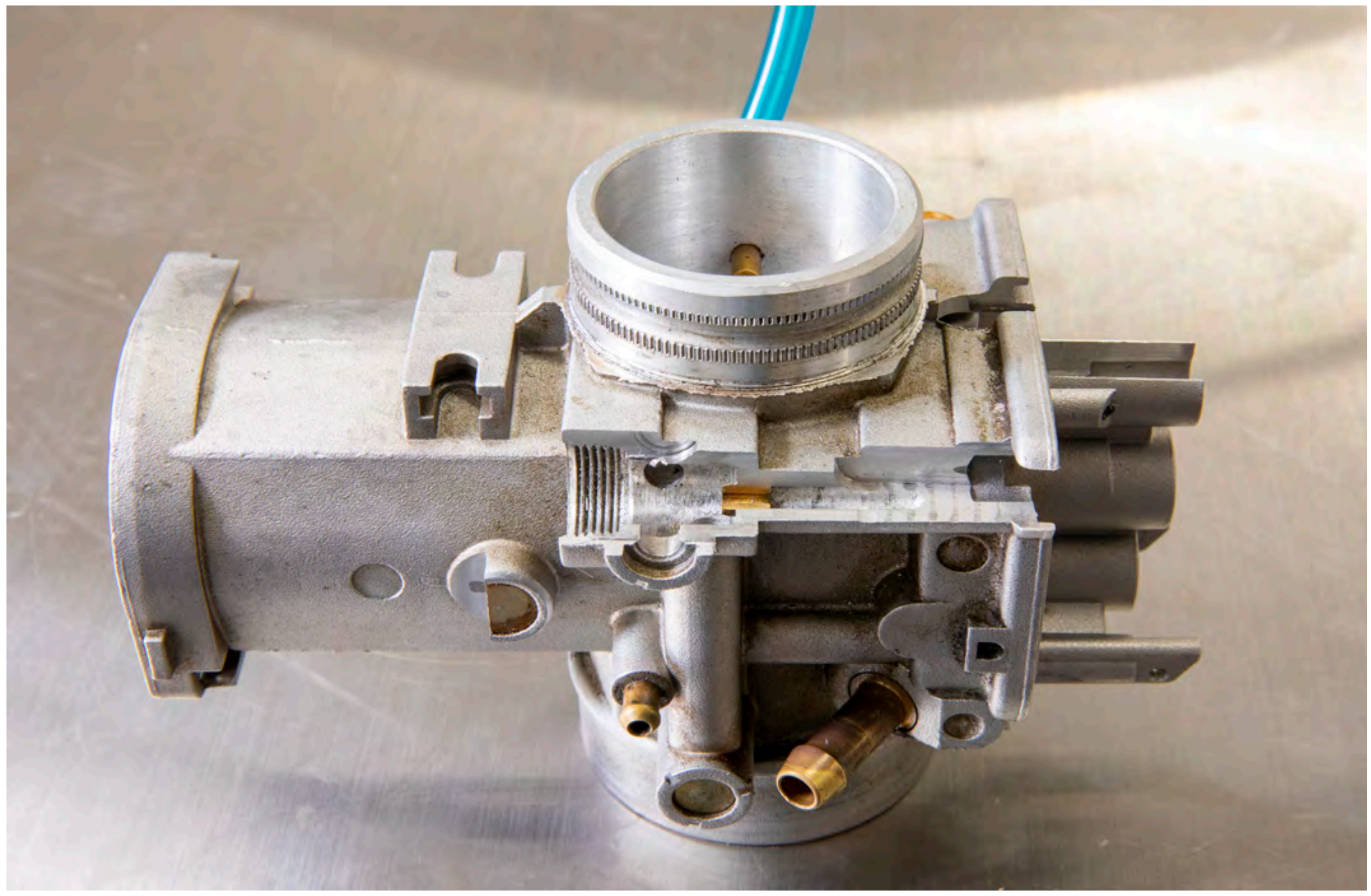


Figure: 3 Machining to Access the Interior Passageways

this results in excellent accuracy when we are presenting cutaways of how all the internal components interact with each other. Once the individual components are modeled, we now assemble each component into a larger sub-assembly. The process is much like we would assemble any component on the workbench. We apply “Mates” to each individual part to locate its position and orientation in relationship to all of the other parts. It’s a very rewarding process. It is much like building a real airplane where you can see each of the components coming together one at a time to make up the whole assembly. Once you have assembled and mated each of the components you can now see how they interact with each other. Or more importantly, how they might inappropriately interact. Most of the individual components can be measured and modeled using simple tools like micrometers and calipers. However, in order to accurately 3D model the internal passageways of the carburetor, it requires that we sacrifice one of the carburetor bodies and several other components by cutting away sections with the milling machine to uncover hidden internal passageways.(Figure: 3) Once we have machine the way excess material we can now measure the internal passageways in order to create a more accurate 3D model. And

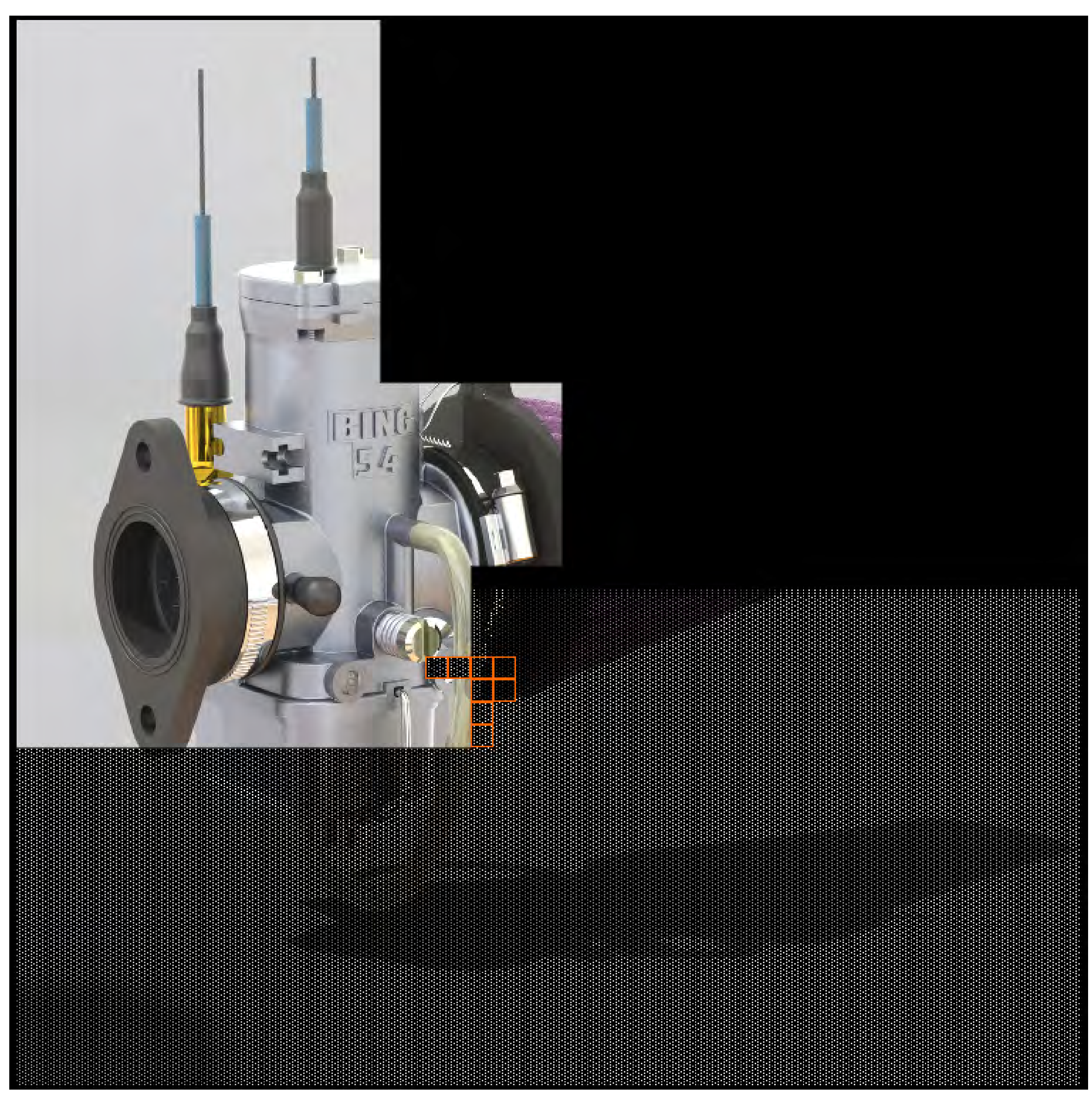


Figure: 4 Redering in Progress

after all, it is the internal modeling that is by far the most elusive and as a result, most important. Once we have created the basic 3D model using SolidWorks, we are kind of, just getting started. Each and every 3D modeled component requires that we apply textures and appearances to each of the individual components in order to give a photo-realistic appearance to each of the parts that make up the subassembly. The goal is to make the parts look as real as possible. The ultimate compliment is when readers think that the renderings are actually photographs. And although, SolidWorks has a lot of great and helpful presets built in, most of the time it requires that we modify the individual appearances to give a more realistic appearance. But like in real life, how a component looks depends a great deal on lighting. The same holds true in solid works. We have to apply lighting, and environmental conditions whenever we render a digital picture. This process can be rather tedious and time-consuming. Even with years of practice, it often takes several dozen renderings in order to come up with an ideal life like photograph. The computer processing power necessary to be able to create these renderings is staggering. Even with our very fast computer with an 8 core processor, most of the renderings that we generate for these type of articles, will take between 20 and 60 hours of continuous processing time for a single picture.(Figure:

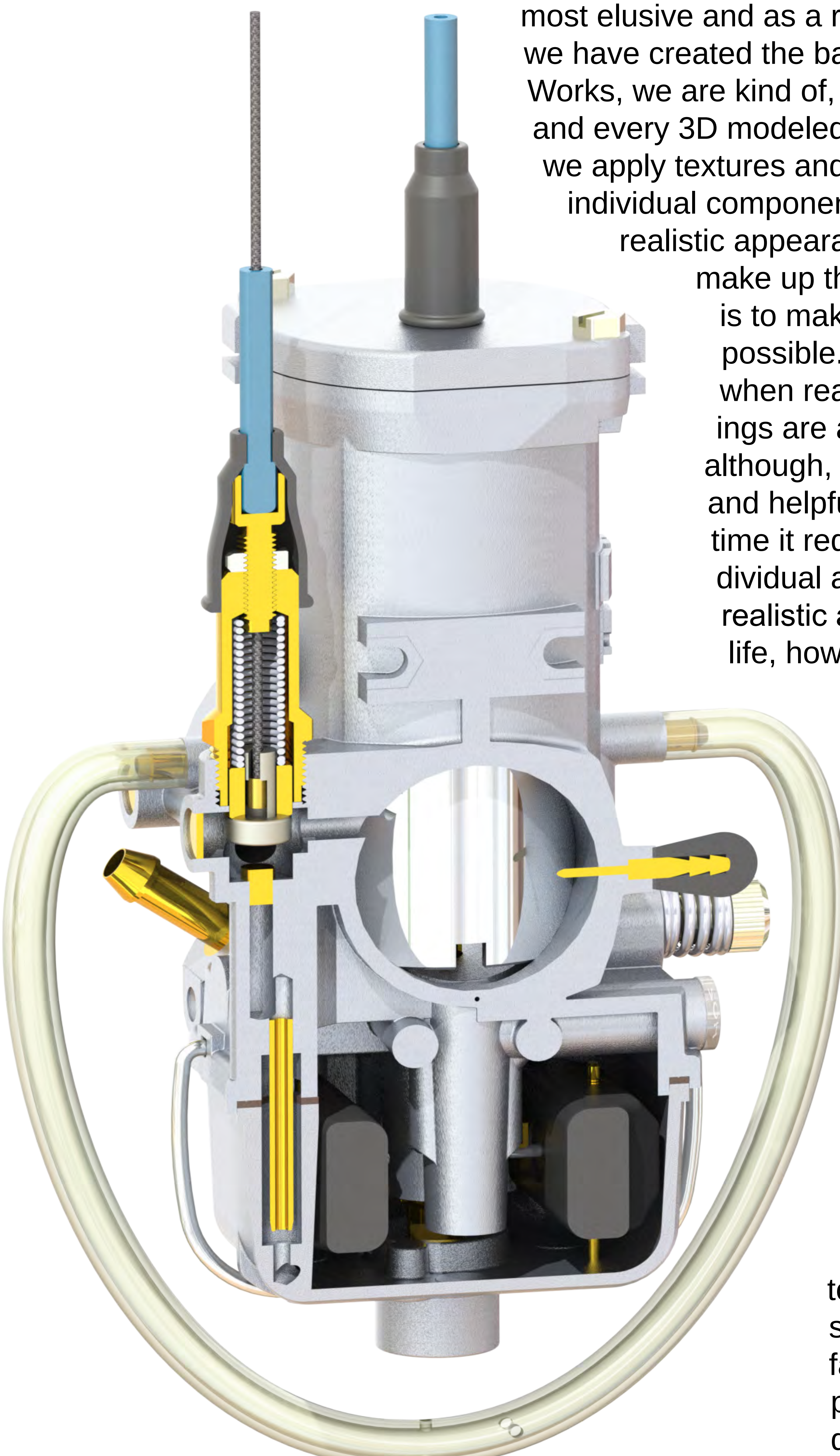


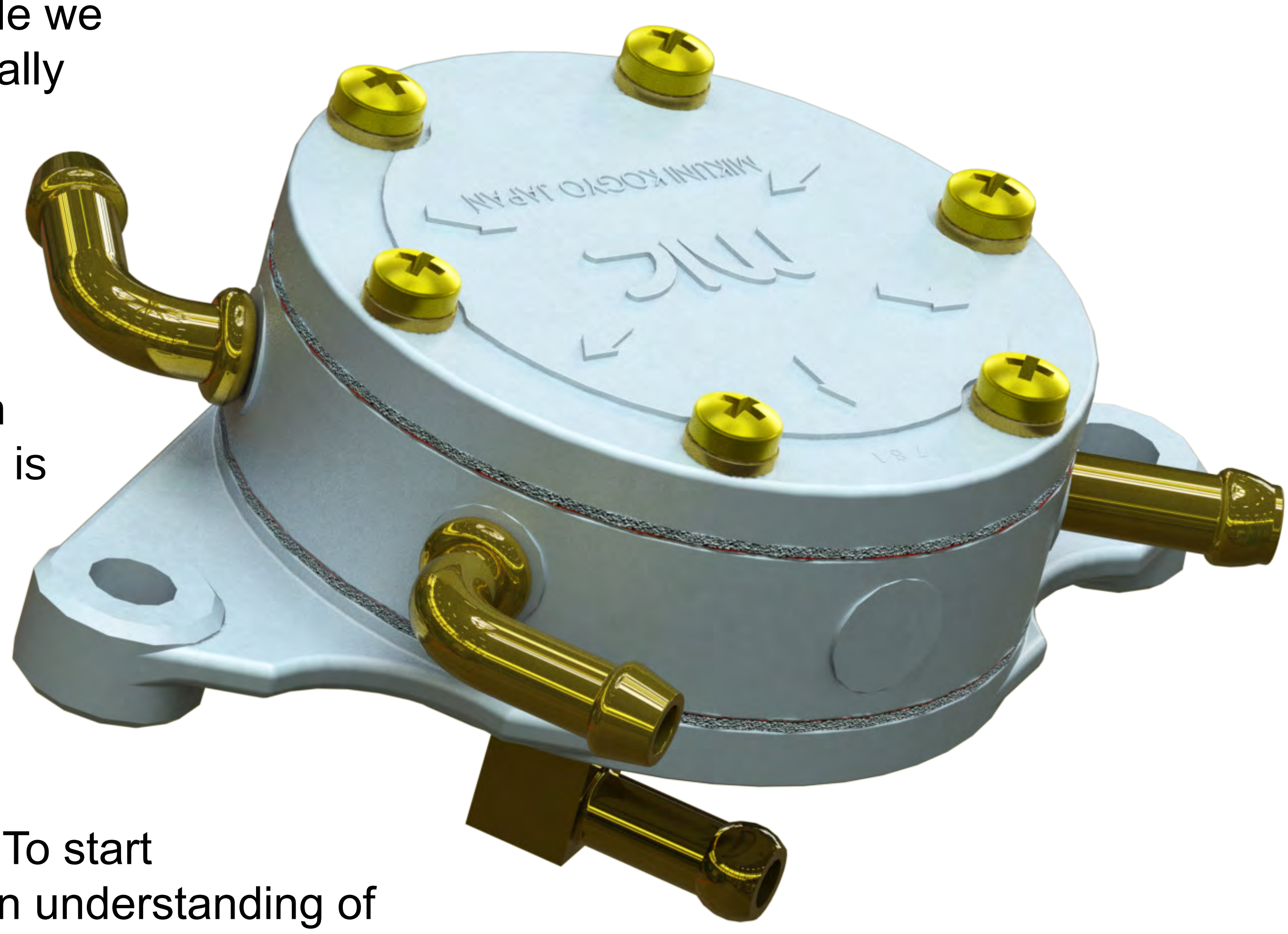
Figure: 5 Cut-A-Way Rendering

Figure: 6 300% Scale 3D Printed Carburetor

4) Having even one item on the assembly incorrectly textured can make your rendering unusable. We normally will generate some low resolution renderings that take only a few hours to ensure that the final rendering will not be a waste of computing time. Using solid works to generate 3D models also allows us a myriad of different capabilities that make for really useful training aids. We can create transparencies to be able to look right through a part into the internal workings of a component. It allows us to do cut away sections to also look at the internal workings while simultaneously choosing individual parts that will not be included in the cutaway section. (Figure: 5) And speaking of training aids, we typically take all of the effort that we have in generating these 3D models and create actual 3D printed models for use in the classroom.

On occasion, we get a bit carried away as we did with the CV carburetor when we printed a 300% scale model of the Bing CV carburetor. (Figure: 6) having the ability to 3D modeling solid works really opens up a whole host of opportunities. For you would-be airplane designers out there, we can't stress how useful and powerful the SolidWorks software is. And although the learning curve is quite substantial, the end result and capabilities are well worth the effort. With EAA members free access to the software you can't possibly go wrong.

The pulse fuel pump is by far one of the most prolific and widely used fuel pumps for two-stroke engines. One of the big advantages of this type of fuel pump is its simplicity and reliability. Although there are moving parts within the fuel pump, those moving parts consist of 4 pieces of clear Mylar plastic. Two are pumping diaphragms and two are check valves.(Figure: 1) These parts are fixed in place and as a result see little to no wear. This category of pulse type fuel pump is populated by a wide variety of styles as well as different manufacturers. For this article we will concentrate specifically on the dual outlet Mikuni fuel pump used on the majority of the 2 cylinder Rotax 2 stroke engines.



Mechanical actuation of this type of fuel pump is accomplished through the use of air pressure. This concept may seem a little bit confusing at first, but let's look at how this brilliant concept is put into play. To start with, we need to have an understanding of how the two-stroke engine functions. For all practical purposes a multi-cylinder two-stroke engine can be thought of as two individual engines connected via a crankshaft. Each cylinder is operating independent from the other. A seal is placed around the crankshaft and in-between each cylinder to prevent crankcase air pressure from leaking from one cylinder to the other. The sealing method by which this is accomplished varies depending on each engine design. This sealed crankcase system is critical to the design of the two-stroke engine. As the piston travels upward on the compression stroke, it is not only compressing the fuel, air, oil, mixture within the combustion chamber, but it is simultaneously increasing the volume below the piston and within the crankcase. As we all know, if we increase the volume, this will result in a lowering of the pressure within the crankcase. This lower pressure is what draws the fuel, air, and oil mixture through the carburetor, into the intake manifold, and subsequently into the crankcase. Many pilots operating two-stroke engines are often surprised to learn that the fuel, air, and oil mixture does not go directly into the cylinder, but rather enters the engine underneath the piston while it is at the top of the compression stroke. This is the method by which the two-stroke engine lubricates the majority of moving parts within the lower end of the engine. The crankshaft, main bearings, connecting rods, wrist pin bearings, cylinder walls etc. All rely on the oil that is mixed with the gasoline at a 50 to 1 ratio. Without this sealed crankcase we could not create the pressure differential necessary to be able to draw fuel, air, and oil into the crankcase.

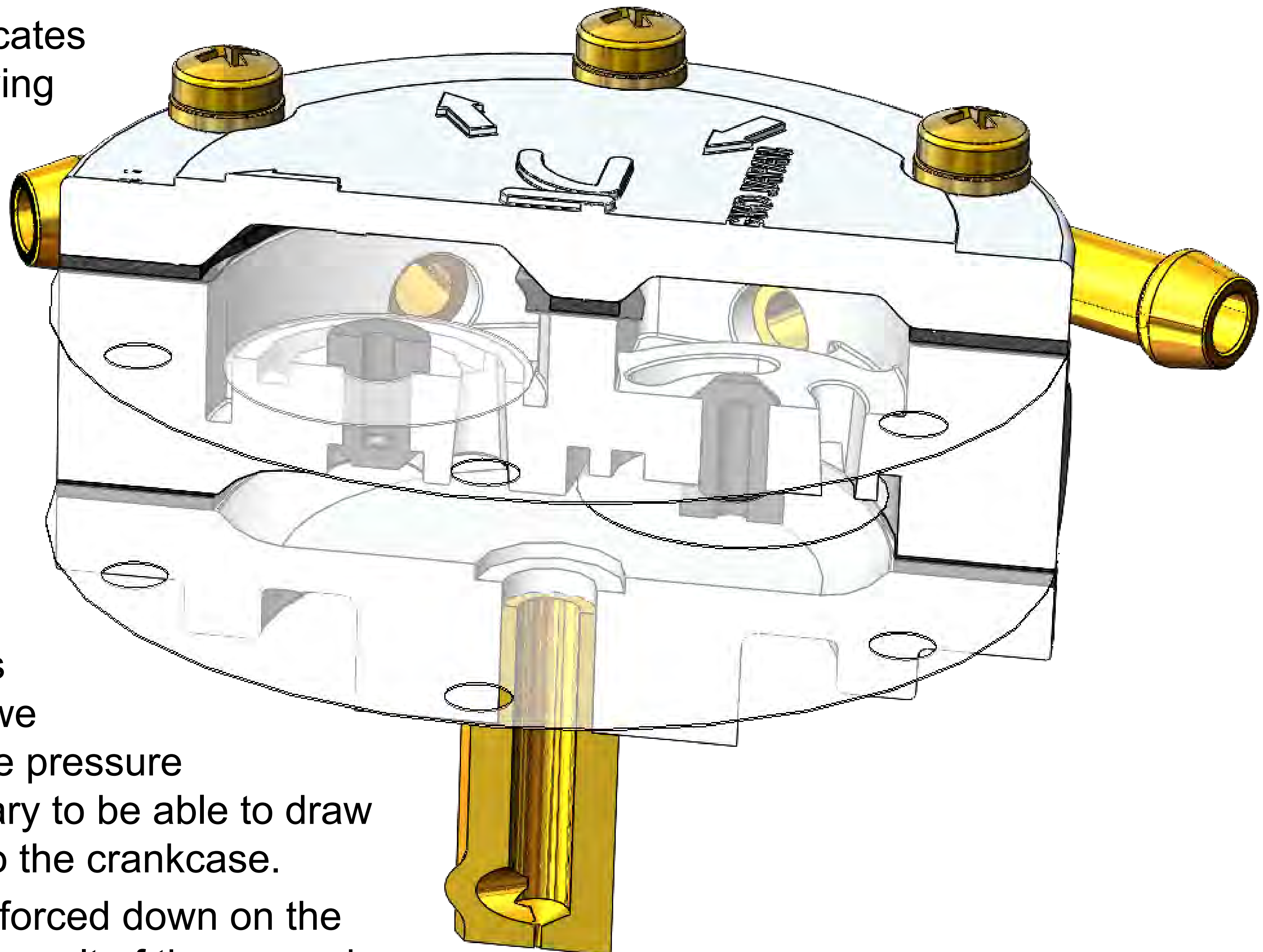


Figure: 1 Mikuni Fuel Pump

As the piston is forced down on the power stroke, as a result of the expanding combustion gases, it is decreasing the volume within the crankcase and causing an increase in pressure. This positive pressurization of the crankcase is now used to force the fuel, air, oil mixture up through transfer ports located on the side of the cylinders. These transfer ports are just as they sound, a passageway by which the fuel, air, oil can be transported around the piston and into the combustion chamber. As the piston reaches the bottom of it stroke, it begins the process all over again. This results in a significant change in pressure within the crankcase. Positive pressure, then negative pressure. Up to 6500 pulses per minute depending on the RPM of the engine.

The Mikuni fuel pump is very similar to many other mechanical type fuel pumps utilizing a mechanically operated diaphragm and two check valves. The primary difference is, that rather than attaching a mechanical arm to the diaphragm and operating it through some type of cam mechanism, we are simply using air pressure to actuate the diaphragm. The diaphragm within the Mikuni fuel pump is made from a flexible Mylar type of material. Once installed in the fuel pump, and pinched between the gaskets and the body segments of the fuel pump, there isn't really much movement of the diaphragm. However, if you're moving the diaphragm 6500 times per minute, it doesn't take much travel. Even if your engine is burning 4 gallons per hour, that works out to only .0013 fluid ounces per stroke.

In (Figure: 2) we can see the pressure cycle within the fuel pump. By running a hose from the crankcase of the engine to the diaphragm side of the fuel pump, we can take advantage of this pressure differential to actuate this Mylar diaphragm.

There are basically 6 chambers within the fuel pump.(Figure: 3) The fuel inlet chamber is where fuel is drawn into the fuel pump from the fuel tank. As the diaphragm is influenced by the negative pressure from within the crankcase it draws the diaphragm down increasing the volume within the pumping chamber. It simultaneously closes the outlet check valve, and opens the inlet check valve. This draws fuel from the inlet chamber into the pumping chamber. As the pressure is reversed, the inlet check valve closes and the outlet check valve now opens. As the cycle begins to repeat itself, the fuel that has been pumped into the fuel outlet chamber is prevented from returning back to the pumping chamber by the Mylar check valve and the process repeats itself.

As the fuel enters the carburetor on the engine, it raises the floats to shut off the float bowl needle and seat. The pressure within the fuel line will begin to increase. As this pressure increases within the fuel outlet chamber, the pressure against the Mylar check valve and the pressure within the pumping chamber will reach an equilibrium reducing the pumping action. At this point the pump will only move the diaphragm the amount necessary to accommodate the fuel flow for any given power setting. In reality, the fuel pump has a significantly greater amount of capacity than is necessary

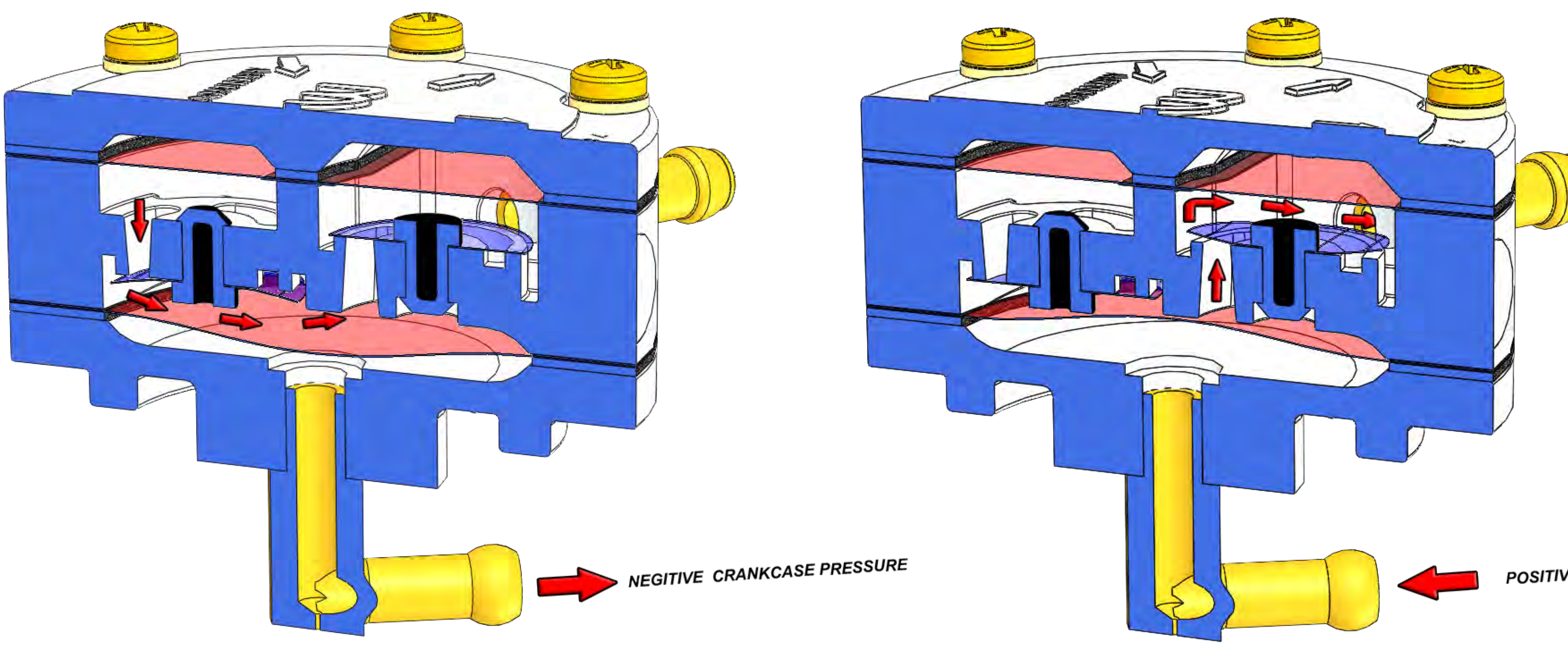


Figure: 2 Fuel Pump Operation Cycle

to run the engine. Having the fuel pump not deliver the minimum required amount of fuel for a particular power setting would inevitably end up in the inability to supply the subsequent amount of fuel subsequently lowering the float level, resulting in a leaning of the mixture. At a minimum, this would likely result in engine damage and more likely than not, engine stoppage. Unfortunately, it is the engine stoppage that normally gives the operator the first indication that something has gone awry with the fuel pump. The more effective way for monitoring the health of the fuel pump, is by monitoring fuel pressure in between the fuel pump and the carburetor. A lowering of pressure, is an indication of the pumps lack of effectiveness.

If, in-flight, you see a fuel pressure drop, this could indicate a pulse pump heading towards failure. If installed, this would be the time to turn on the auxiliary fuel pump

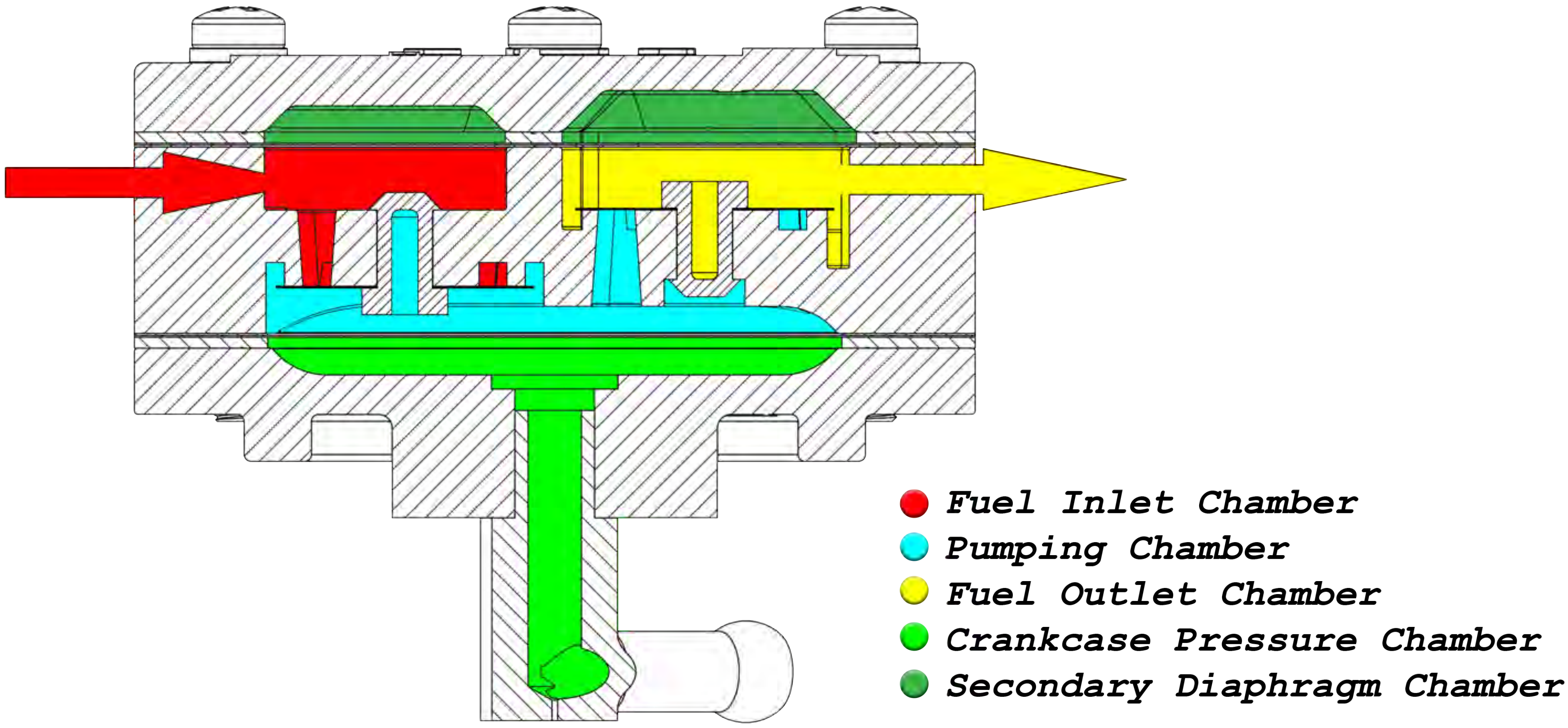


Figure: 4 Internal Pumping Chambers

and immediately head for home.

If an additional auxiliary fuel pump is used within the system it is typically placed in series with the pulse pump. You can see in the diagram, that by applying pressure to the fuel inlet chamber, the pressure from the auxiliary fuel pump can simply off seat the inlet check valve, flow into the pumping chamber, and then offset the fuel outlet check valve as the fuel flows unimpeded through the fuel pump. Under normal circumstances even a failure of the Mylar check valves within the pump would not prevent the free flow of fuel from an auxiliary fuel pump through the pulse pump itself.

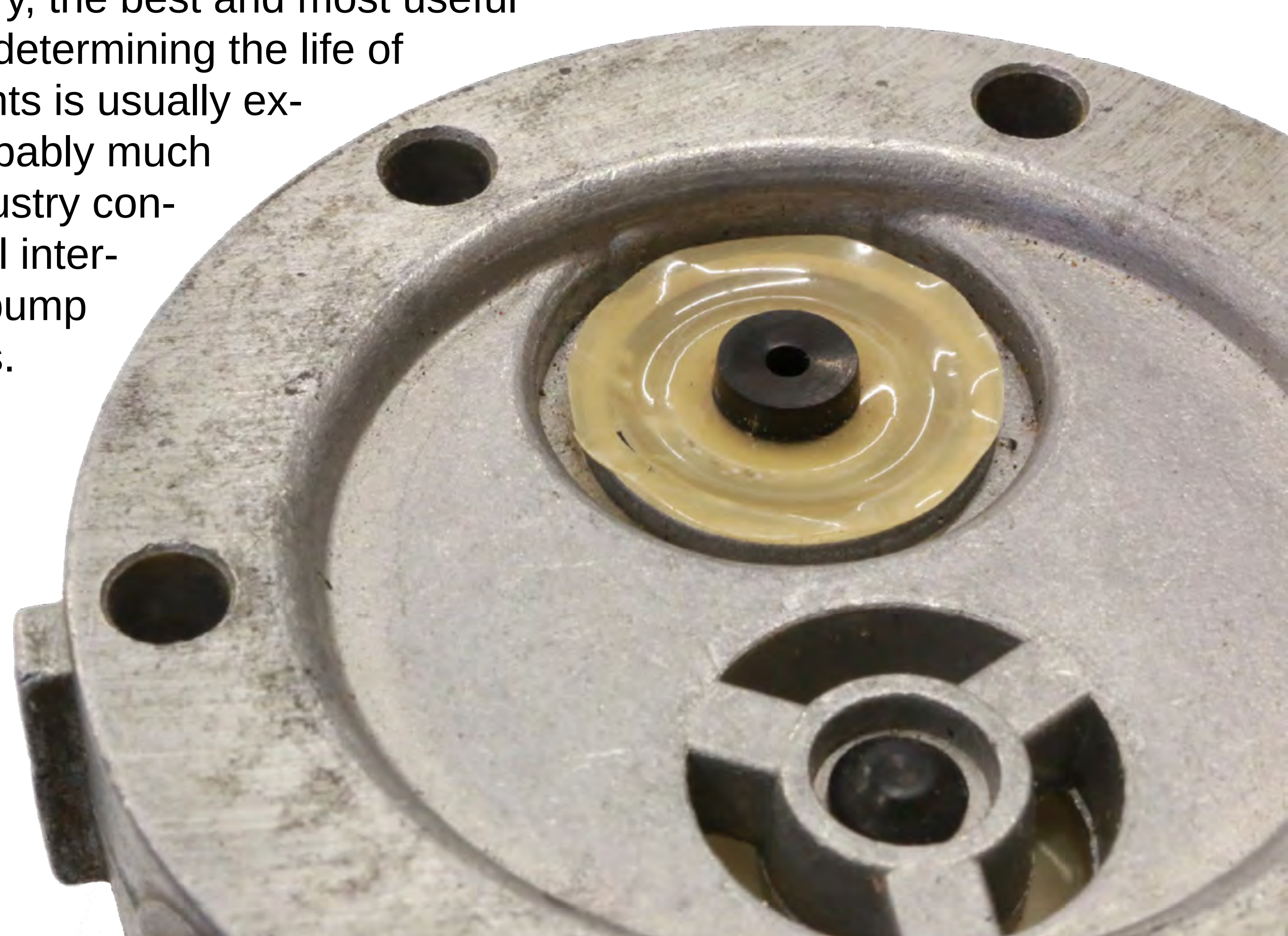
Although the pumps have a great reputation and the potential for nearly flawless operation, we still continue to see mistakes made, that result in fuel pump failures. When it comes to system failures within the experimental aircraft world, fuel systems in general, still continues to be one of those areas where we could use some significant improvement. In this article we have tried to lay down the theoretical foundation on the inner workings of the pulse type fuel pumps. The next step is to identify the more predominant failure modes and some installation do'es and don'ts. In part 2 of this article, we will discuss more of the practical aspects of installation, maintenance, and troubleshooting. Armed with the knowledge about both the theoretical and the practical aspects of these fuel pumps, you should be up to operate your two-stroke engine with complete reliability and confidence in the fuel pump that is so critical to the operation of your engine.

In part 1 of this article we discussed in epth the theory of operation of the Mikuni dual output pulse pump used on the ma-jority of Rotax 2 stroke engines. In this part were going to take a more pragmatic and practical look at the fuel pump, its operation, maintenance, troubleshooting, and some of the more common failure modes.

The big advantage of having a fuel pump designed with the diaphragms and literally no other moving parts is it's simplicity. This contributes signi icantly to the reliability of the overall operation of the fuel pump, however, with simplicity comes the typically common counterpoint of missing redundancy. It's one of those scenarios where a single point failure can break the chain of reliability. Everything has to work perfectly or the system breaks down.

In most engines we have a plethora of life limited parts. The fuel pump is no exception. Any time that we are talking about rubber, plastic, gasket material etc. We are talking about components that by their very nature have a limit to their life. The chemical composition changes over time and with exposure to UV, heat, chemicals, and oxygen. (*Figure: 1*) Shows an example of the fuel pump check valve showing extreme deterioration from age. The type of exposure and the length of time that each one of these materials are exposed to will determine the life of that individual component. Although there has been a signi icant body of research regarding the durability of each type of material used in industry, the best and most useful metric that we have in determining the life of any of these components is usually experience. Although probably much longer, the general industry consensus for the overhaul interval for the Mikuni fuel pump seems to be, two years. By design there is very little wear on the mylar check valves and diaphragms. Since most aircraft owners operate less than 200 hours per year the total operating hours seems to have little

Figure: 1 Aged Check Valve



effect on the overall reliability of the fuel pump. It is simply the exposure to the elements and the chemicals that is the controlling factor for the life limit. In our diagrams for the purposes of clarity, we have rendered the normally clear diaphragms with a red tint and check valves with a blue tint. (*Figure: 2*)

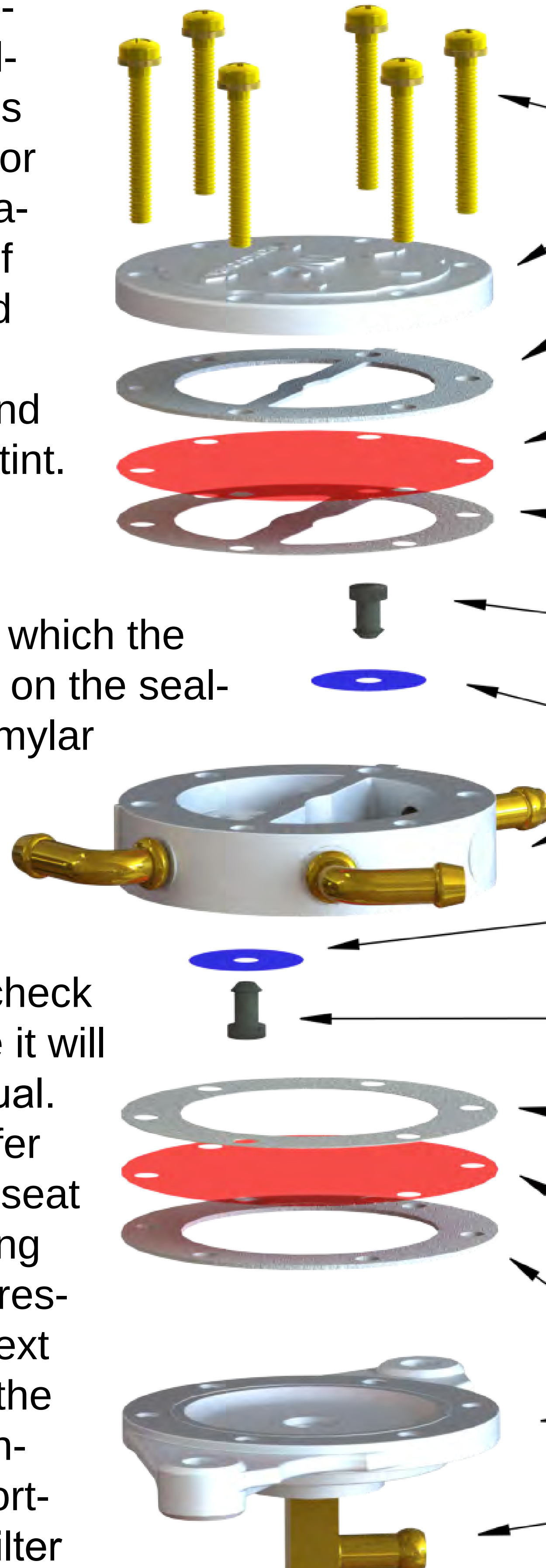


Figure: 2 *Fuel Pump Exploded View*

The basic principle by which the check valve works, relies on the sealing surface between the mylar check valve and the machined face of the pump body.(*Figure: 3*) If any contamination is able to get between the check valve and its sealing face it will render the pump ineffectual. The fuel will simply transfer back and forth under the seat of the check valve resulting in little to no actual fuel pressure. This brings us to next very important aspect of the pulse type fuel pump, contamination. It is very important that you have a fuel filter in the system, but not just in the system, rather the filter needs to protect all aspects of the fuel system including the pulse pump. Placing the fuel filter after the fuel pump has left it vulnerable to contamination and subsequent failure.

Even with a fuel filter installed in the fuel line there is still a significant hazard that lurks waiting to decapitate the effectiveness of your fuel pump. The majority of two-stroke engines operate on automotive fuel. Many of them operate utilizing alcohol within the fuel. Alcohol has a notorious tendency to attract moisture and cause corrosion within the fuel system. (*Figure: 4*) shows an example of a carburetor float bowl on a Rotax 582 exposed to alcohol and water in the fuel system over a few months of storage. If this type of corrosion is present within the carburetor, how is it possible that the fuel pump that supplies that same fuel is unaffected? Corrosion that deteriorates the sealing surfaces of the check valve, would at best, reduce the effectiveness of the fuel pump, and at worst, result in engine stoppage. In this particular example, the result was an engine seizure shortly after takeoff. A good preflight inspection including pulling the float bowls for inspection would have revealed the potential hazard. But remember, finding corrosion in the carburetor should leave you wanting to investigate the rest of the fuel system including the fuel pump.

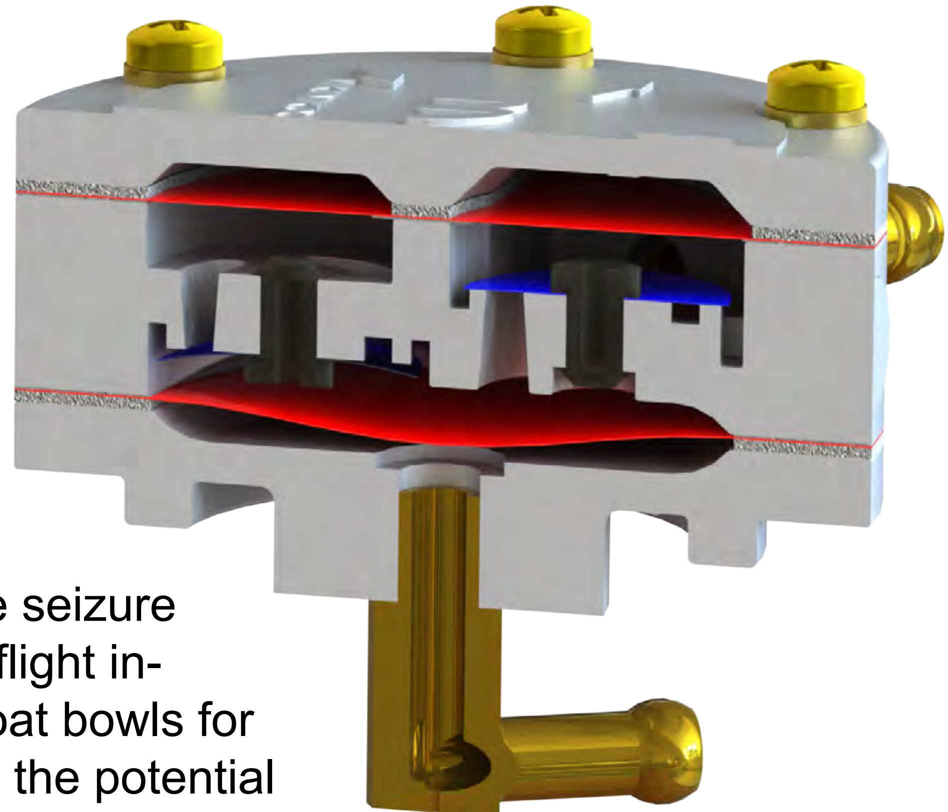


Figure: 3 Fuel Pump Cut-a-Way

There are several installation procedures that can improve the reliability and decrease the potential for failure. Because the fuel pump relies on pressure pulses from the engine as the heart of its operation, we need to look at any potential failure modes within this system. First of all, there is a potential for liquid lock within the pulse chamber body. If the pulse chamber was to become filled with a fluid, the density of that fluid would restrict the movement of the diaphragm and the ability of the fuel pump to pump fuel. Mounting the fuel pump with the pulse line connector above the level of the crankcase pressure port will allow fuel and oil to return to the crank-

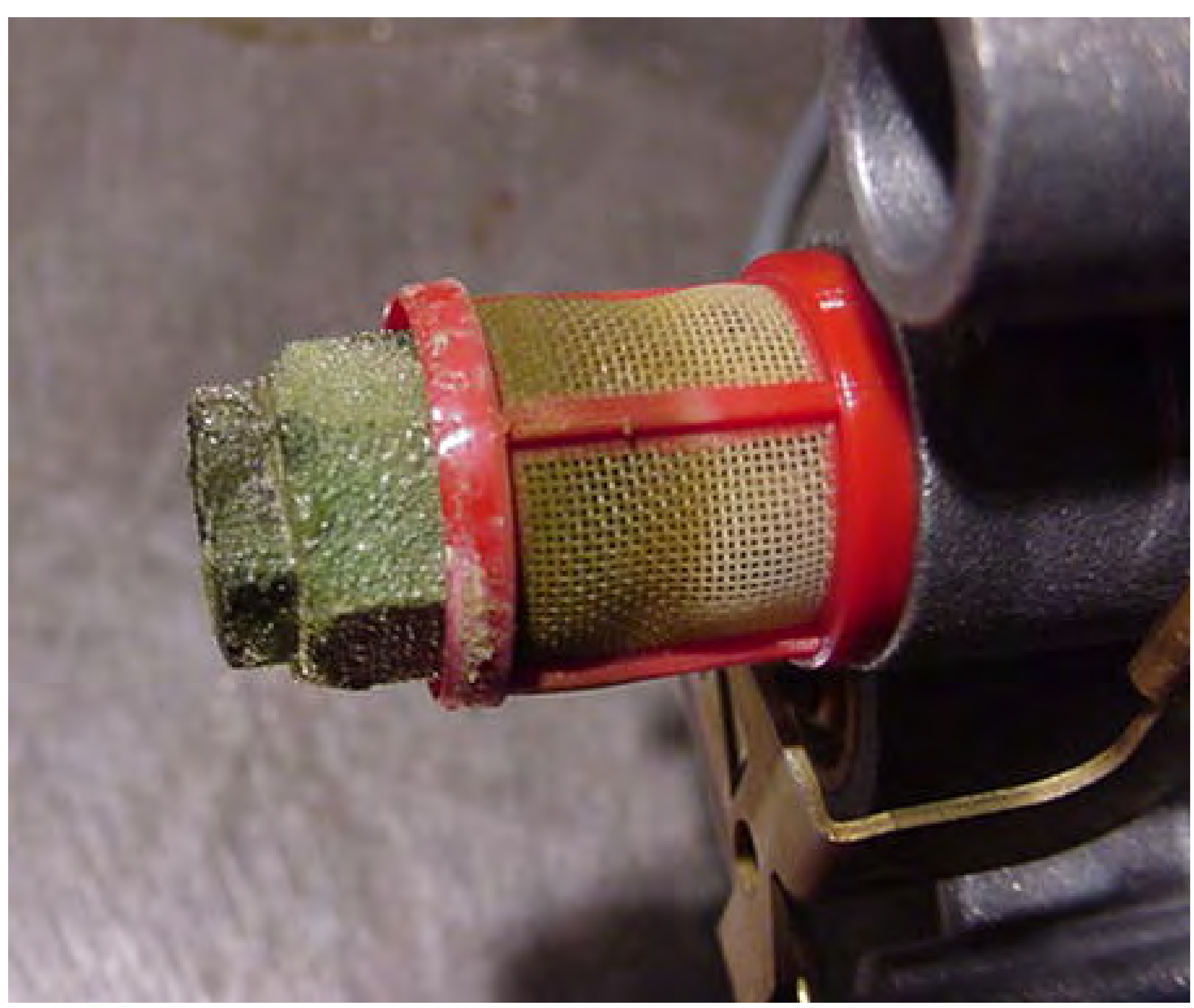


Figure: 4 Alcohol Induced Corrosion

case and prevent
it from collecting within the pulse line
and the pulse chamber body.

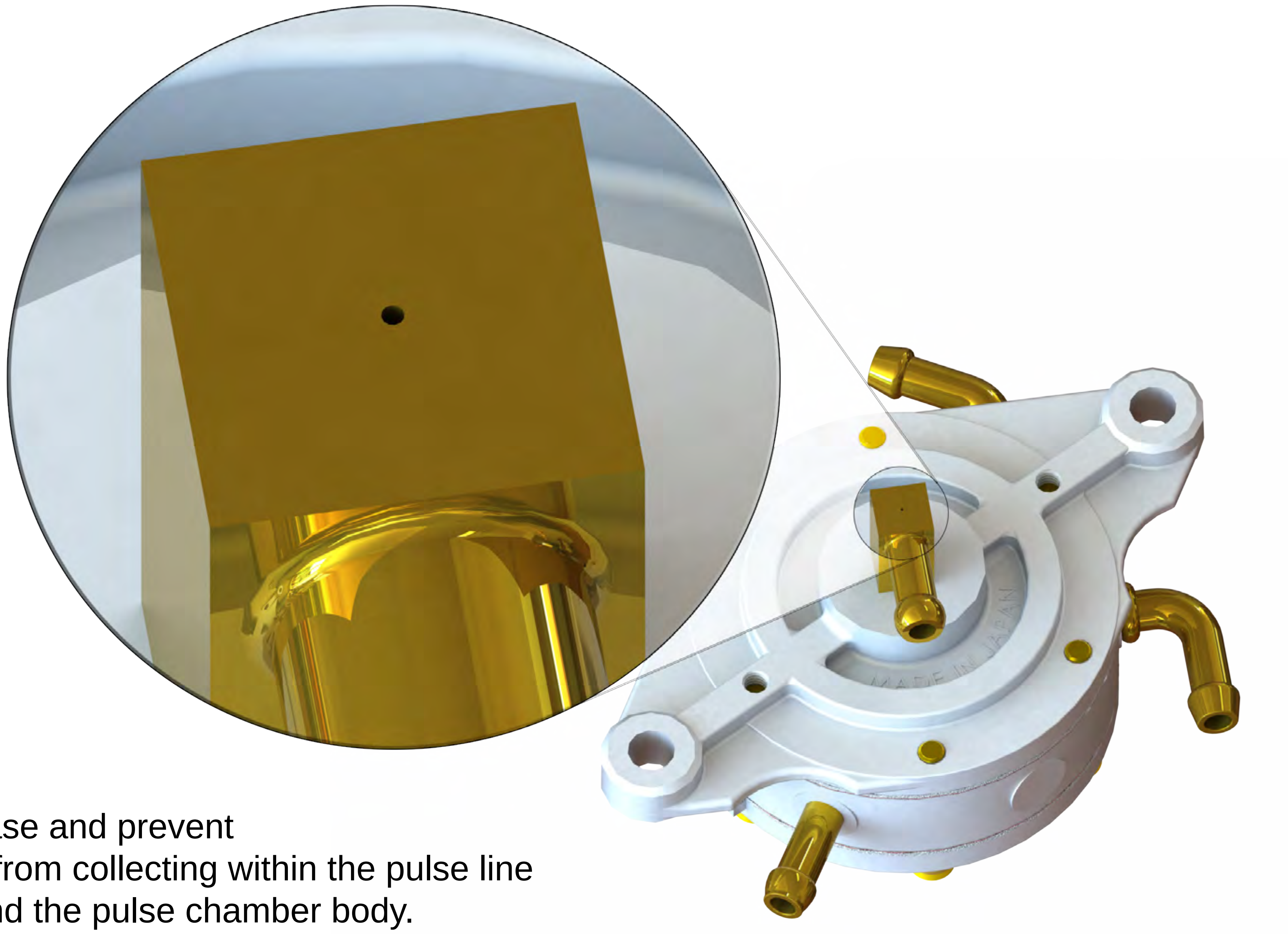


Figure: 5 Vent Hole

Although nearly impossible to see, (*Figure: 5*) located within the pulse line connector is an extremely small hole drilled in the brass fitting. This hole is used to allow any excess fuel or oil to be bleed from the pulse line and fuel pump body. It is important to ensure that this hole does not become plugged from debris, paint, or wax. Disconnecting the pulse line and blowing through it gently will reveal whether or not the vent hole is plugged. Do not use high-pressure air to try and dislodge any contamination as it may result in damage to the diaphragms. The fuel pump should be mounted with the pulse line connector positioned facing downward. This will allow any fuel or oil to be able to drain from the fuel pump. On the single outlet fuel pumps, (*Figure: 6*) the vent hole is located within the casting. If positioned with the hole facing upward it creates a reservoir capable of capturing water from rain or even washing the aircraft. This reservoir of water can leak into the body of the fuel pump housing causing a liquid lock.

The other important issue with regards to the pulse line, is the length and type of hose used from the engine to the fuel pump. During normal engine operation there are in the neighborhood of 100 pulses every second. You can imagine that if the length of the pulse line was, say a mile long, those pulses would be long dampened out with virtually no measurable pulse occurring at the other end. Of course, we're not going to use a mile long hose to hook up our fuel pump, but it is important that the hose be limited in its length. Additionally, a hose that is soft can act like a balloon and absorb the pulses reducing the effectiveness of the fuel pump. Most aircraft suppliers, make available "pulse line" which is more rigid and designed specifically for this application.

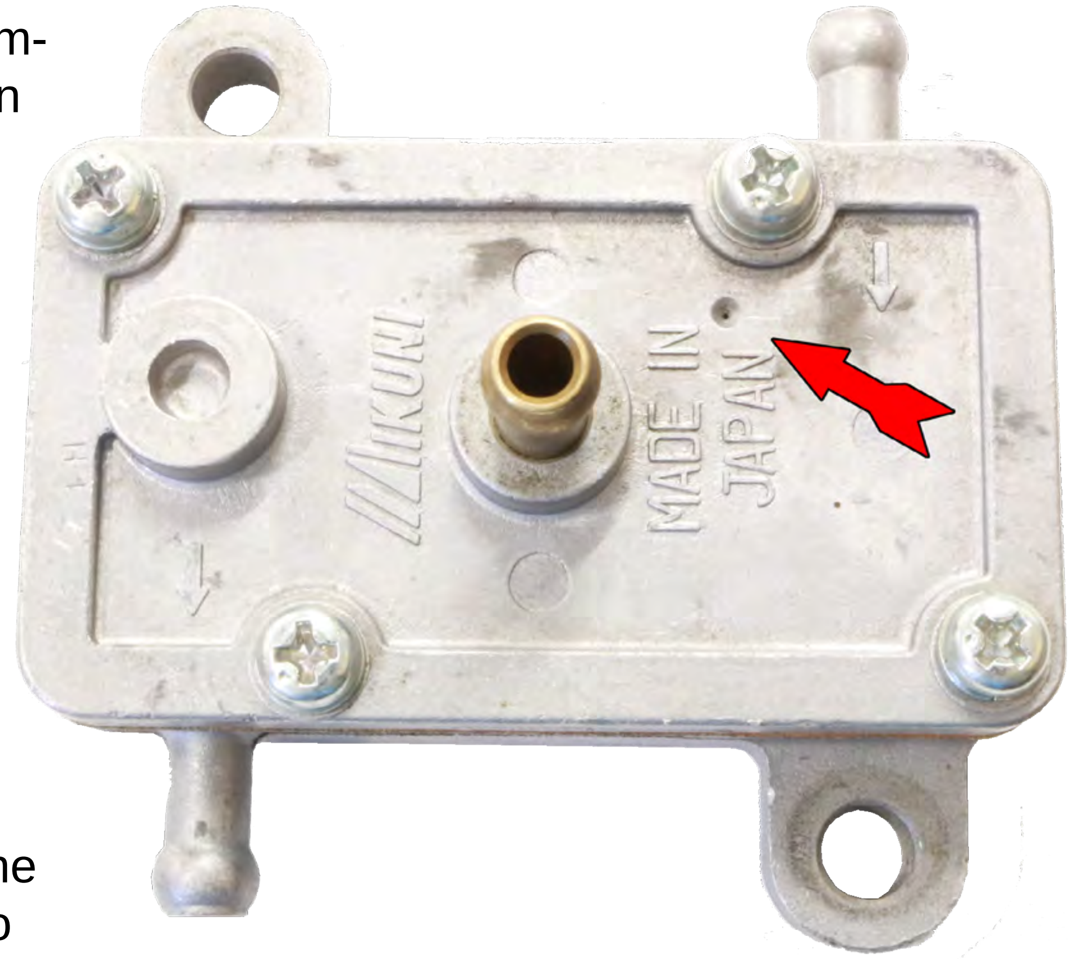


Figure: 6 Single Carb Fuel Pump Vent Hole

Another standard practice is to mount the fuel pump on the airframe rather than on the engine itself. The primary reasons are to reduce both the heat and the vibration that can be transferred from the engine to the fuel pump. Excessive heat can lead to vapor lock within the fuel pump as well as cause premature deterioration of the gaskets, diaphragm, and check valves. Excessive vibration can lead to impaired performance due to the inertial forces of the fuel counteracting the normal workings of the diaphragm and check valves.

If you are setting up a new aircraft fuel system, using these installation and maintenance procedures will lead to a much more robust and reliable fuel pumping system. Understanding the basic underlying principles of operation coupled with these real world practical applications should leave you with more confidence in this type of fuel pumping system on your two-stroke powered aircraft.

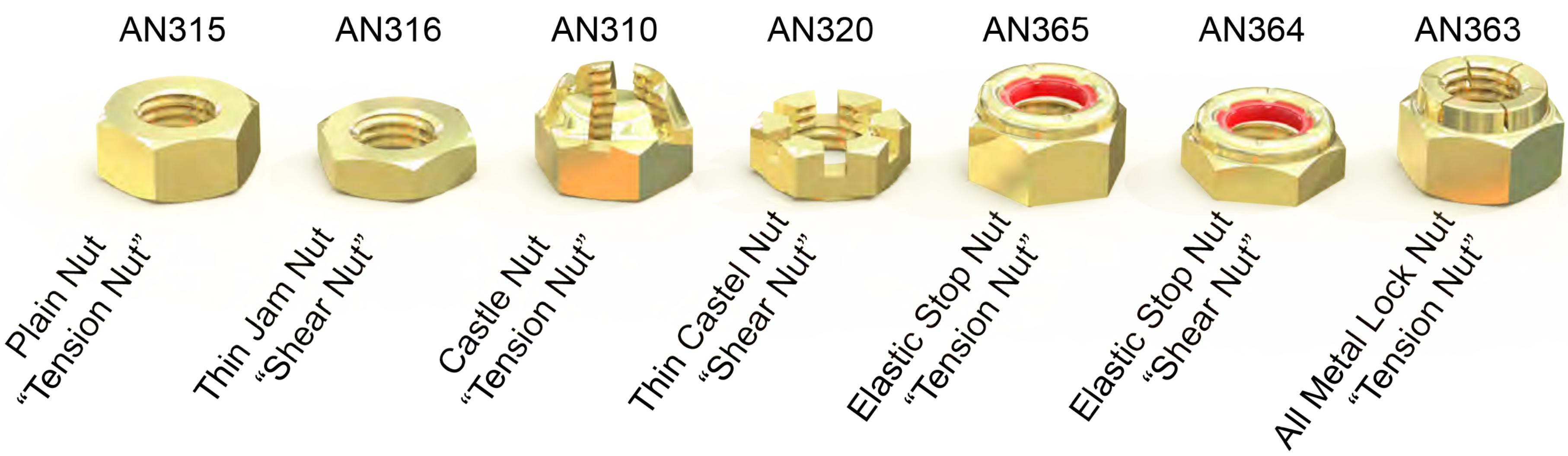


Figure: 1 Most Common Nuts for Experimental Aircraft

In the October 2018 issue of Sport Aviation, we had an article called "Bolt Basics". Although, the article on bolts did not provide any groundbreaking revelations on bolts, it did spur a significant amount of praise for helping to simplify and clarify many of the confusing points about bolts and break down the conversation to the essentials for the experimental aircraft builder. And with that premise in mind, let's examine the same for aircraft nuts. Like bolts, there are only a handful of nuts that make up the vast majority of nuts used on experimental aircraft. (Figure: 1) And although each of these nuts have a cross reference to an MS (Military Standard), and NAS (National Aerospace Standard), for simplicity, we will be dealing with just the part numbers for the original AN (Army Navy Standard).

The AN315 plain nut (Figure: 2) has no locking feature and as a result is almost always used in conjunction with some additional locking device. The most common locking device would be, either the lock washer or loctite type thread locking product. Because the plain nut / lock-washer combination is one of the least reliable locking systems, it has a list of areas where we would not use the combination. Flight critical primary or secondary structures. Where failure would permit the opening of a joint to the airflow. Where the nut is subject to frequent removal. Or where subject to corrosive conditions. Additionally, when the nut is used with a lock-washer against soft material the use of a washer as a buffer is common practice. One

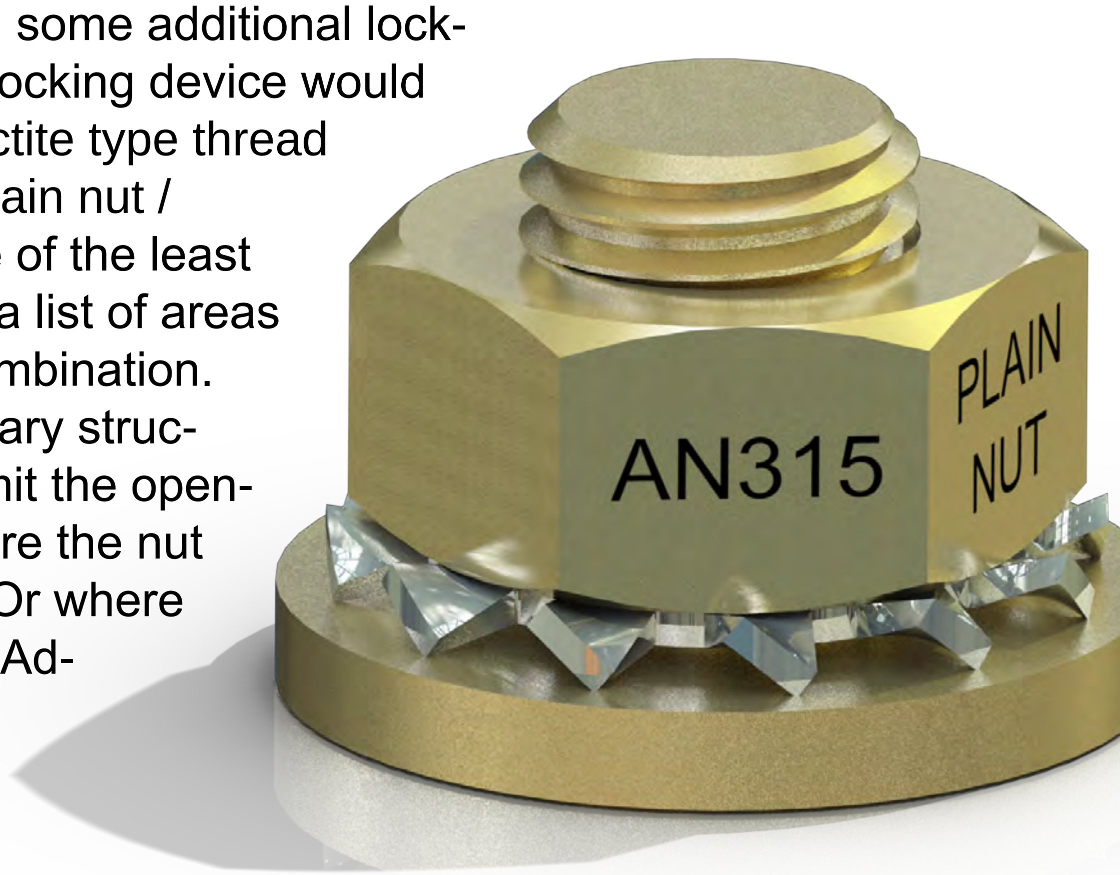


Figure: 2 AN315 Plain Nut

of the more prolific uses of the AN315 or AN316 is on electrical wiring. Attaching a ring terminal to a switch, circuit breaker, or buss bar allows for the easy installation of the plain nut / lock-washer in normally difficult to reach areas, with a reasonably secure system, considering the loads imposed on wiring.

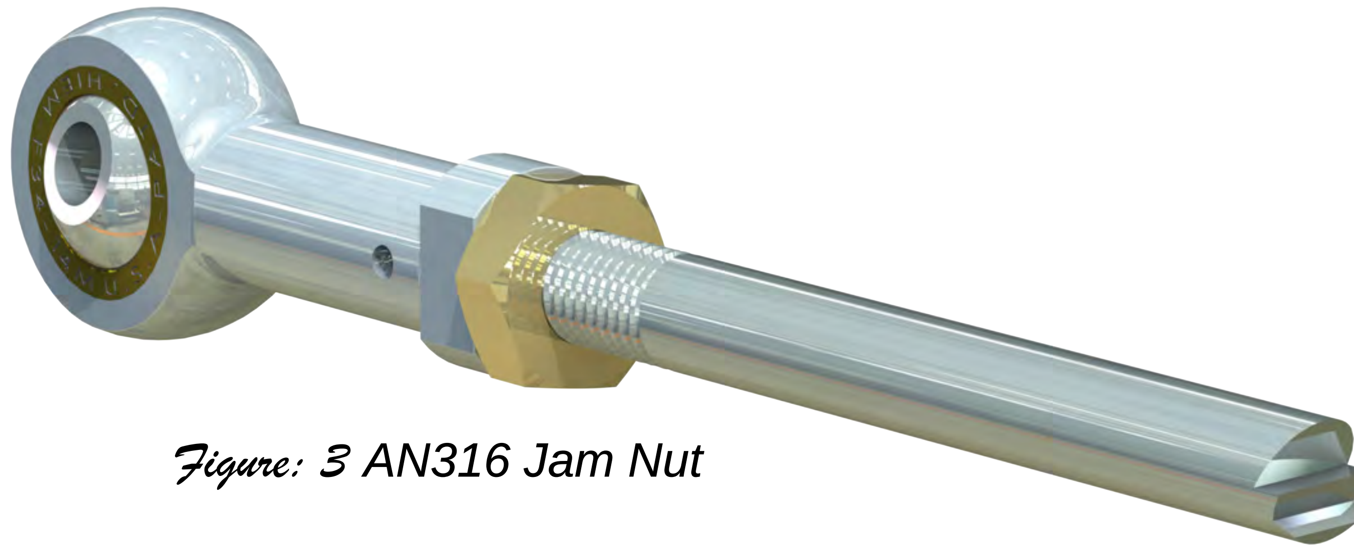


Figure: 3 AN316 Jam Nut

The AN316 "Jam nut" or "check nut" is the thinner version of the AN315. You may also find it used in many of the same applications as it's big brother the AN 315 plain nut where the tension loads are minimal. In these cases, the same caution's and rules for its use apply. And although the AN316 is also a plain nut without a built-in locking device, it is, itself, often used as a locking device. The most common application here is as a lock nut to secure a rod end to a push-rod. (Figure: 3)

The AN310 castle nut (Figure: 4) is used in conjunction with a cotter pin to provide a greater level of security in preventing the nut from backing off. The two primary applications for this combination is for nuts and bolts that are subject to rotation, and for applications where removal and re-installation of the nut is frequent. An example of this might include components of removable or folding wings. The AN320 castle nut is the thin version of the AN310 castle nut. This is a castle nut used when the bolt is loaded in sheer and most commonly coupled with an NAS sheer bolt that has a smaller cross section of threads suited specifically for sheer only applications.

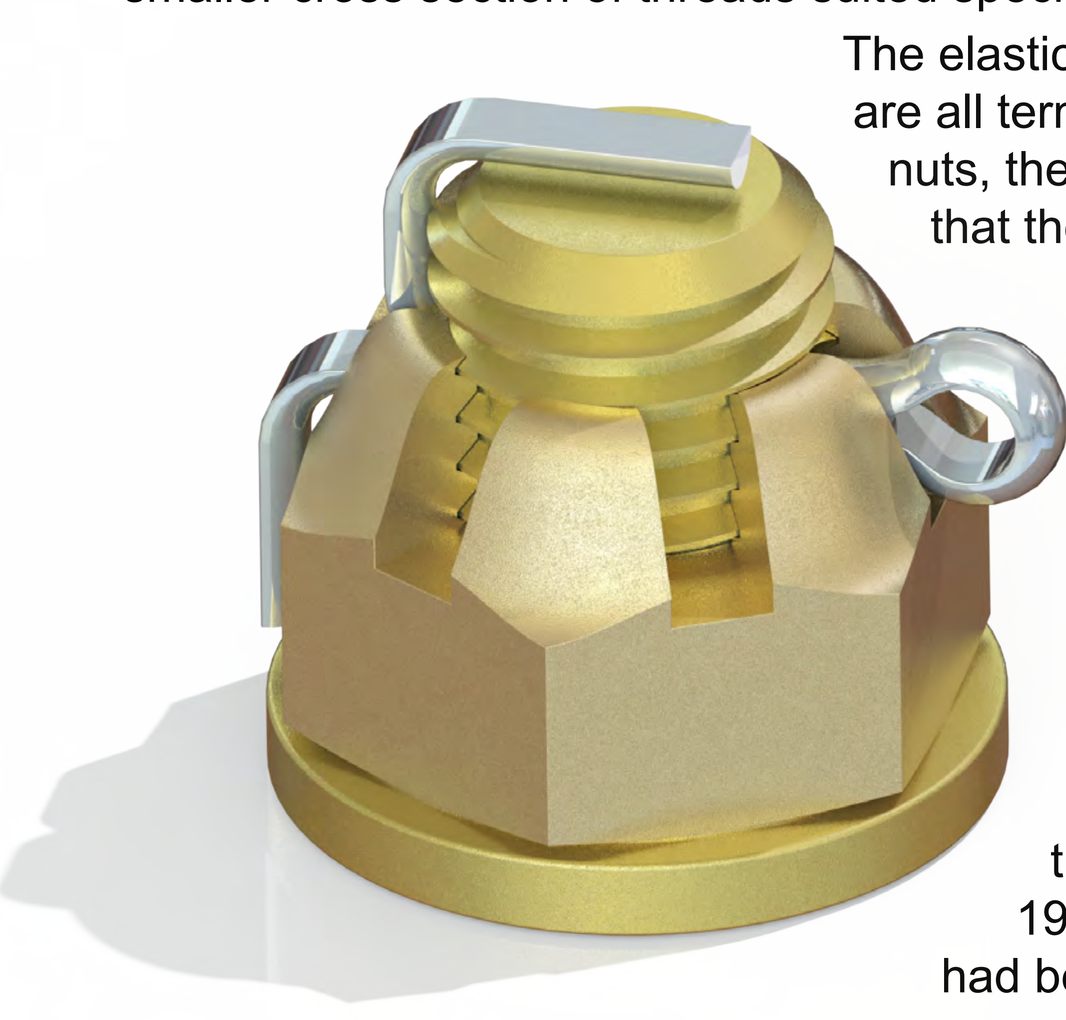


Figure: 4 AN320 Castle Nut

The elastic stop nut, nylock nut, or fiber lock nut, are all terms to describe the most prolific of all the nuts, the AN365. Most people are not aware that the term "elastic stop" nut is a trade name. You may have heard the term "esna nut", well, ESNA® stands for Elastic Stop Nut Corporation of America. In 1934, Swedish immigrant and inventor Carl Swanstrom, had perfected a threaded fastener able to positively resist the loosening effect of vibration. He called the fastener an "Elastic Stop Nut" because the nut remained "stopped" anywhere along the bolt threads. Although Nylon didn't make its debut until 1938, by the early 40's the use of nylon had become the standard material for the self-locking nut insert. Today there are many manufactures of nylon self-locking nuts, and like motorcycles, tractors, and power tools, the use of color to brand a product is common. If you see a red nylon locking insert, it is most likely from ESNA®, and Greer Stop Nut TM, uses a green nylon insert. (Figure: 5)

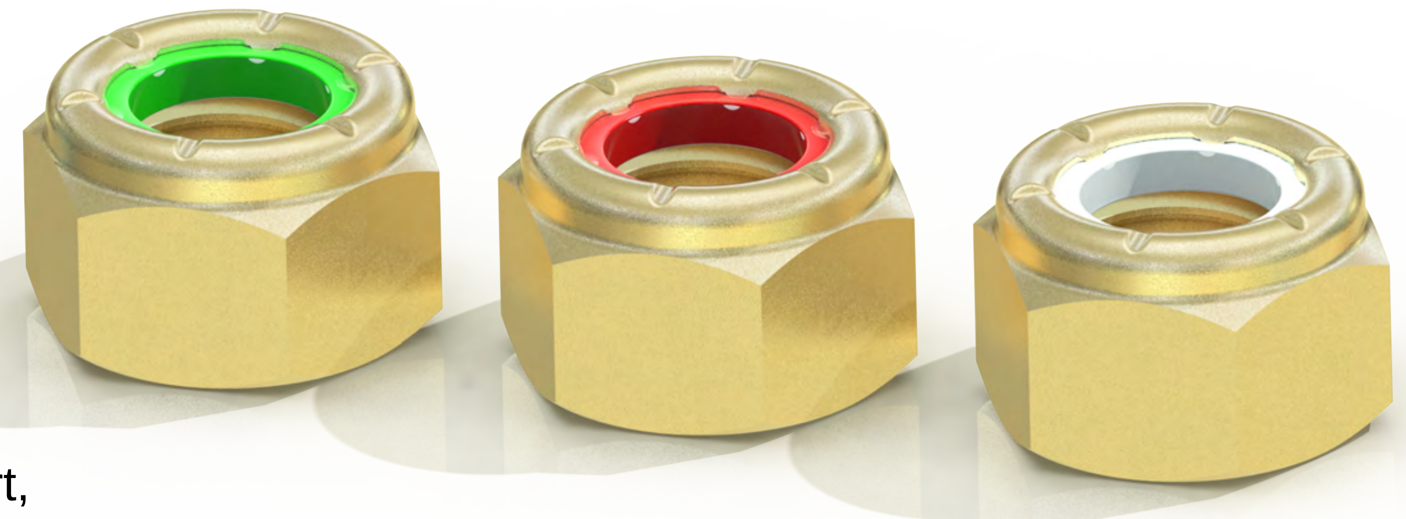


Figure: 5 AN365 Elastic Stop Nuts

For a faster system to function properly, it is important that the bolt - nut combination retain its required torque. A fastener that is properly designed to carry it's required load when properly torqued, may fail from fatigue if it becomes loose and begins to rattle. The reliability of a load carrying fastener depends not only on the strength of the nut and bolt, but on the ability of the system to remain in place and tight. The nylon inserts internal diameter is smaller than the bolt thread and the external diameter. The nylon forms a tight grip on the threads preventing the nut from rotating even under severe shock and vibration. This friction that exists between the nylon and the bolt threads while the nut is being installed, but before it begins seat, is referred to as prevailing torque. AC 43.13-1B, table 7-2, lists the minimum prevailing torque for reuse of elastic stop nuts larger than 3/8 inch. The current wisdom for the smaller size nuts, states that if a nut the can be turned by your fingers or a nut that moves easily with a wrench it should be rejected. According to the ESNA manual, "elastic stop nuts may be reused through more than 50 on-off application cycles". However, this premise is only valid with new or relatively new nuts where the elastic properties of the nylon remain. The two major factors that reduce the ability of the elastic stop nut perform are, age and heat. Like a rubber band, it loses its elasticity over time. When replacing nuts that have been in service several years or an unknown serve life, it is standard practice to replace with new. The other variable is heat. The nylon insert is rated for 250° F. When working in what we call "firewall forward applications," we normally op for the AN363 all metal lock nut (Figure: 6) over the elastic stop nut for obvious reasons. The AN363 like its counterpart the AN365 elastic stop nut is also a self-locking

Figure: 6 AN363 All Metal Lock Nut

nut and can also be reinstalled multiple times following the same minimum prevailing torque requirements for self-locking nuts. However, unlike the elastic stop nut the all metal lock nuts, because of their construction, tend to remove the CAD plating from the threads as they are removed and re-installed. Signs that the CAD plating has been compromised may warrant replacement of the bolt as well as the nut. At first glance it may appear that the all metal lock nut is a superior nut when considering its self-locking feature. Although the all metal locking nut has its area where it out performs other nuts, primarily, high temperature environments, the elastic stop nut's most important feature is often over looked. It turns out that, though extensive testing, the big advantage of the nylon insert, is that it has been shown to act as a resonant vibration damper, reducing the vibrations present within the bolt that promote the loss of tension. There is a normal tendency of a fastener system loose tension long before the nut begins to rotate. This is particularly prevalent in high vibration environments. This initial loss of tension can be the precursor to the nut losing enough tension to then allow the nut to rotate reducing the tension even further and the onset of subsequent failure. In the ESNA catalog they show a relative performance rating for different types of nuts and their ability to retain tension in these high vibration environments. (Figure: 7) Is a recreation and sampling of some of the test results. Not all applications require this high degree of attention to proper tension, but on those applications that do, it is critical that proper torque be applied during installation. These applications invariably involve the use of a tension type nut. The distinction between the tension type nuts and the shear type nuts is readily observable buy the nut height and number of threads. The thinner shear type nuts are used in applications where they ***are not*** subject to significant tension loads. Using a shear nut in a tension application is a recipe for disaster. Likewise, torquing a shear nut to the

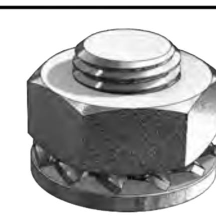
Relative Vibration Performance		
Elastic Stop Nut		100
All Metal lock Nut Beam Type		53
All Metal Lock Nut Distorted Type		19
Castle Nut With Cotter Pin		8
Castle Nut With Spring Pin		38
Castle Nut With Lock Wire		18
Plain Nut With Spring Lock Washer		5
Plain Nut With Toothed Lock Washer		1
Plain Nut		1

Figure: 7 Relative Vibration Performance Chart torque values used for a tension nut would certainly cause a failure of the nut. The reduced thickness and thread count necessitates a lower torque value when tightening. AC 43.13-1B, table 7-1 is a good resource for standard torque values. Remember that your manufactures manual is the bible. The standard torque value chart is only used when manufacture s data is not available. Although there are literally hundreds of different types of nuts. These that we have discussed in this article make up the vast majority used in experimental aircraft. Its a good idea to have some on hand for your next maintenance task. Not surprising, Aircraft Spruce has a couple of kits that contain nuts with just the right assortment of sizes and types for the average aircraft owner builder. Who knew, that a simple subject like aircraft nuts could be so interesting.

A special thanks to EAA member and Rainbow Aviation Intern Samuel Newcomer for his assistance in 3D modeling of graphics used in this article.

Oleo Strut Basics

An oleo strut is a pneumatic air–oil hydraulic shock absorber. The primary purpose of the oleo strut, as you are probably already aware, is to absorb the landing loads on an aircraft. The force, which the aircraft structure is subject to, can be expressed in Newton's 2nd law of physics F = M A or Force = Mass X Acceleration. Acceleration is simply the change in velocity over time. If we can double the time interval for deceleration of the aircraft through the landing gear by lengthening the shock strut, you can see that we can reduce the total force exerted on the structure by half. This is the basis for incorporating the long struts on STOL (Short Takeoff and Landing) aircraft like the Just Aircraft SuperSTOL and the Fieseler Storch. Watching these aircraft performing short field operations, you can see what appears to be near vertical approaches, culminating in a very impressive squat of the aircraft as the long stroke landing gear struts absorb the landing loads.

Although there's been many variations upon the oleo strut, there is some particular genius in its design. The basic physics incorporated in the operation of the oleo strut is what has made it so popular in so many different designs from the smallest aircraft to the largest. This basic design concept (Figure: 1) is so efficient that even the most modern of aircraft use the same basic principles that adorned aircraft landing gear designed and built as far back as the 1930s.

> ***"It is the fluid and only the fluid that is responsible for the struts' amazing ability to absorb these landing loads. A strut that has lost its fluid is virtually useless."***

Let's look at the basic operation of the oleo strut. (Figure: 2) Inside the strut we likely have a combination of Mill-H-5606 hydraulic fluid and dry air or nitrogen. The primary job of the air located in the upper chamber of the strut is to act as a spring. And the primary job of the hydraulic fluid, which is located in the lower chamber of the strut, is to regulate and transfer the loads from the lower half to the upper half of the strut and subsequently into the airframe. Located in between the upper and lower sections, but attached to the upper portion of the strut, is an orifice (Shown in Green). This orifice restricts the flow of hydraulic fluid from the lower half to the upper half of the strut. This basically lengthens

Figure: 1 Oleo Strut

the time interval during the compression stroke created by the landing gears impact with the ground. Many early strut designs simply stopped at this point using a fixed orifice to control the fluid transfer from the lower to the upper half of the strut. Later designs improved upon this concept by incorporating one more component called the metering pin (Shown in Pink) which takes the design to an entirely new level. This metering pin is attached to the lower portion of the strut and is tapered starting at the top getting wider as it approaches the bottom section of the strut. This metering pin is co-located within the center of the orifice essentially creating a variable sized orifice. When the strut is fully extended, the gap between the orifice and the metering pin is relatively large allowing fluid to flow rapidly. According to Newton's 2nd law the greatest amount of force imposed onto the landing gear structure will be at the point where we have the highest amount of deceleration (initial impact). As the rate of strut compression decreases, so does the force. This design allows the restriction between the orifice and metering pin to progressively get smaller and smaller essentially maintaining a constant force onto the structure while exponentially decreasing the rate of strut collapse. (Figure: 3) This allows the entire length of the lower section of strut to progressively collapse absorbing the landing loads over the longest time interval possible. It's really quite a brilliant concept. A properly serviced strut is virtually impossible to bottom out because of this increasing restriction. Landing forces that could cause the strut to bottom out would likely result in ripping the strut from the aircraft structure. Recognize that it is the fluid and only the fluid that is responsible for the struts' amazing ability to absorb these landing loads. A strut that has lost its fluid is virtually useless. A strut without fluid is the equivalent of welding the bottom half of the strut to the upper portion strut in the collapsed position. The time interval for deceleration, in this case, drop off dramatically. This, in turn, increases the loads imposed into the structure to also increase proportionally. We often wonder how many of the accidents, where we see a collapsed nose strut, are a direct result of improper servicing or simply loss of fluid.

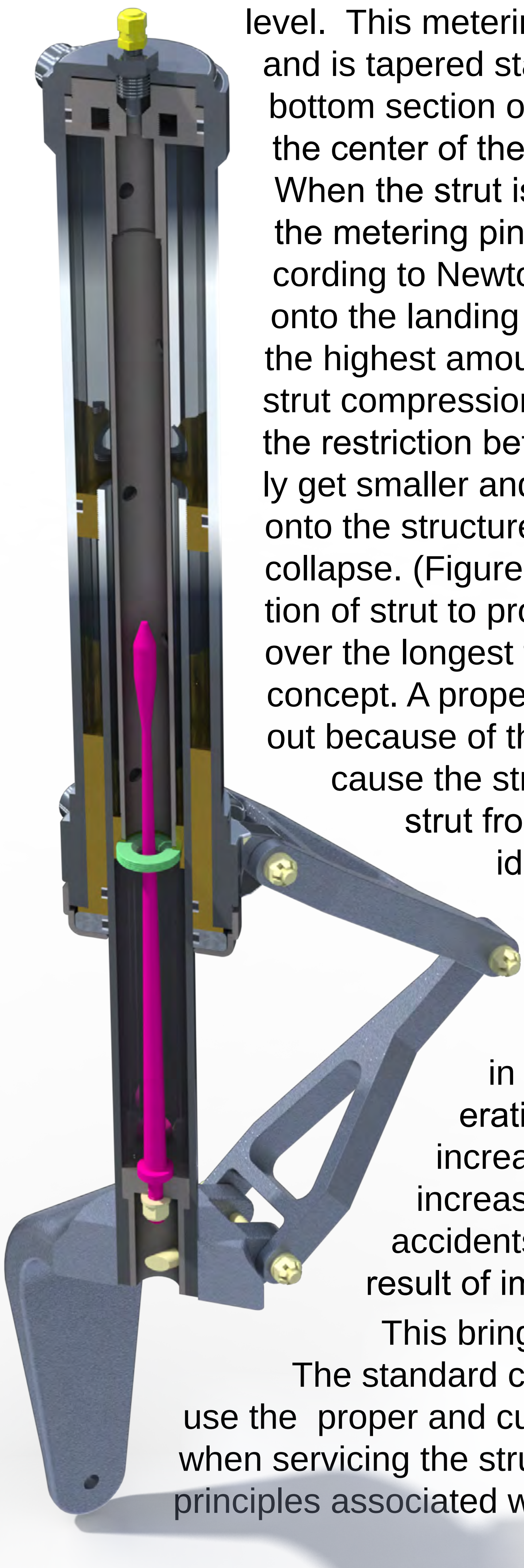


Figure: 2 Oleo Strut Cut-A-Way

This brings us to the topic of proper servicing of the strut. The standard caveat certainly applies here: "You should always use the proper and current service manuals for your particular aircraft when servicing the struts." With this being said, let's consider some basic principles associated with servicing a strut. Keep in mind that during the compression stroke of the landing gear the hydraulic fluid is non-compressible. This essentially means that over servicing the strut with hydraulic fluid could lead to a "liquid lock," thus reducing the overall length of compression, compromising the struts ability to absorb the landing loads. Normal servicing of the strut might require that after adding fluid that we completely collapse the strut ensuring that any excess fluid is squeezed out before we add air or nitrogen. (Use of dry air or nitrogen is to reduce the potential for moisture getting into the internal structure of the strut causing corrosion). With the strut in the collapsed configuration and filled with fluid, the total volume available for air is really quite small. Once you have applied enough pressure to bring the strut up to the proper servicing height (approximately 25% of total stroke), the air simply acts as a spring to return the strut to a height that will allow the fluid transitioning through the orifice and metering pin to dampen shock loads associated with taxing. Because of the small volume of air in the normally serviced position, as the strut begins to extend, the pressure drops off dramatically. If you've ever seen the nose of Cessna sitting higher than normal, you would probably be able to grab the prop and move the nose up and down fairly easily. This simply means that there is a larger volume of air in the nose strut reducing the amount of pressure change as the strut moves up and down. By default, the only way to get a larger volume of air within the strut is to reduce the volume of fluid. The strut is low on fluid! Additionally, there is too much air. If you come out to the ramp and find your strut has collapsed, you have a problem not associated with the amount of air in the strut. The initial urge is simply to service the strut with more air. However, you probably still have the proper amount of air inside of the strut. What has happened is that the strut has lost a small volume of fluid increasing the total volume available for the air. Generally speaking, the most probable source of leaking are the O-rings where the lower strut goes into the upper strut housing. All of the other seals

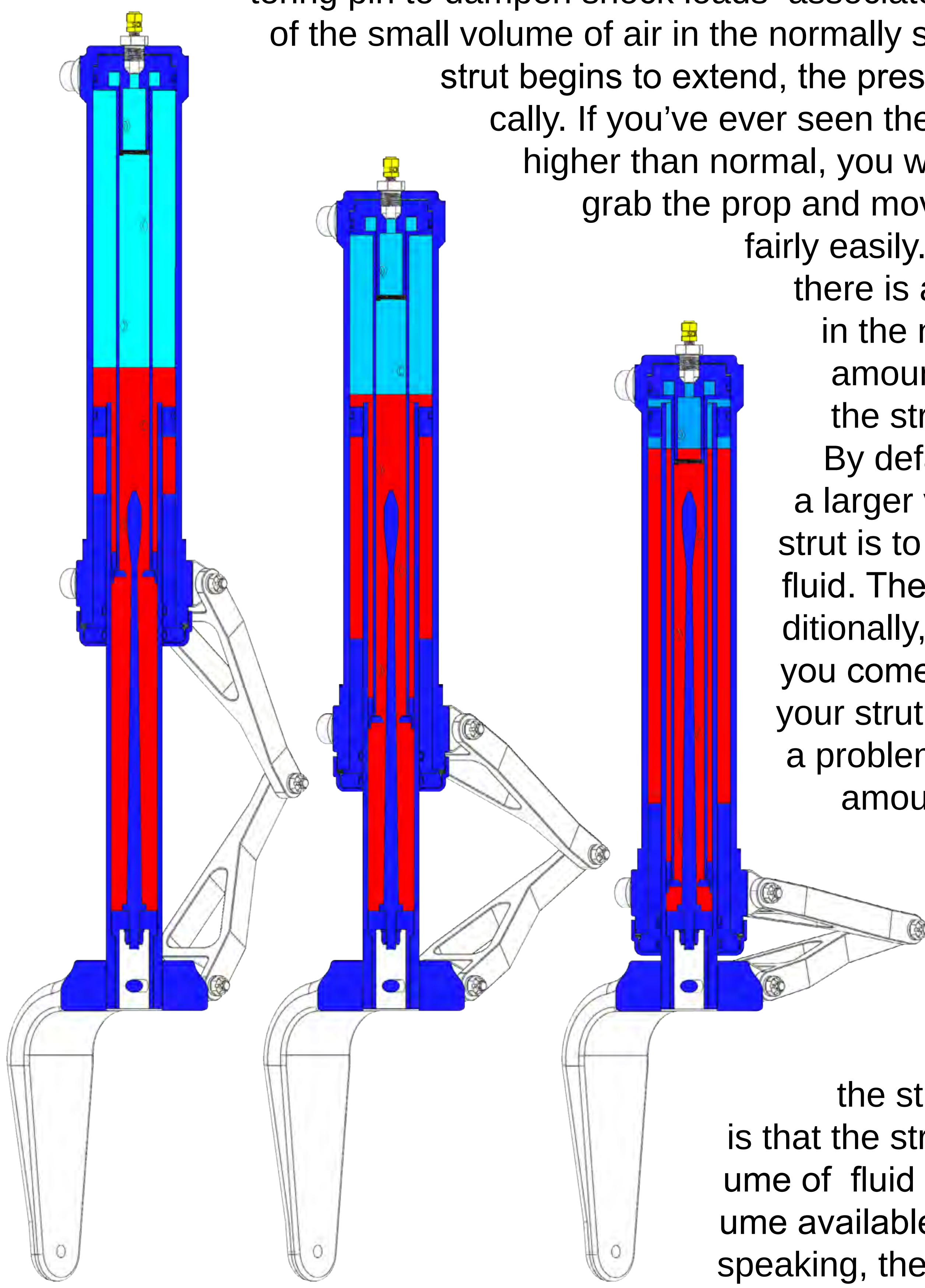


Figure: 3 The Air - Oil Interaction During Operation within the strut are static with a very low likelihood of failure. Because the air is on top of the fluid, the first thing to go is always going to be the hydraulic fluid.

Although it's purely anecdotal, we see a direct correlation with the aircraft owners who wash the aircraft on a regular basis and a higher number of struts seal failures. We hypothesize that the cause of the strut seal failure is due directly to the owner of an aircraft, cleaning and washing, not only the aircraft, but the landing gear struts as well. If you were to completely clean the chromed portion of the oleo strut, you will be left with a very dry surface. As you confidently fly off for your "hundred dollar hamburger" and to show off your nice clean airplane to all of your buddies, you probably don't even realize that you have just set yourself up for a potential strut seal failure. If you inadvertently make a harder than normal landing, you may exercise the landing gear into the portion of the strut that has just been spotlessly cleaned. It is a common occurrence on dry struts, where the landing gear is exercised aggressively, that the internal O-rings will grab onto the nice clean chromed surface causing them to stick and roll. When the O-ring rolls, it normally does it in just one section causing the round O-ring to now take a twist. This twist now becomes a pathway for the hydraulic fluid and air to escape. The result, of course, is a collapsed landing gear strut. Once the O-ring has become rolled or twisted, the only fix, typically, is to disassemble the strut and install new O-rings. Ironically, the aircraft owner who never does any maintenance on his aircraft, and has oil puking out of the engine down onto the struts, never ends up having to replace nose strut seals because of his (automatic strut lubricating system) leaking engine. Of course, we jest, and do not recommend this as your primary solution to preventing strut seal failures. Most aircraft maintenance manuals, and even flight manuals, recommend after washing the aircraft struts to re-lubricate the chrome portion of the strut with a clean rag soaked sparingly in Mill-H-5606 hydraulic fluid. By maintaining a well lubricated strut, the O-rings will slide effortlessly along the chromed surface. It then becomes virtually impossible to roll an O-ring. Many aircraft checklists even incorporate this procedure as a preflight item. This procedure not only re-lubricates the strut and protects it from corrosion, but gives us an opportunity to remove any bugs, dirt, and old dried out hydraulic fluid which may have accumulated. Although not as dramatic a failure as rolling an old ring, dirt and debris that continuously get into the seals of the strut can cause the strut seals to become worn out and eventually leak.

The landing gear struts, in our aircraft, are such an amazing piece of engineering, however, all of that engineering won't do you a "lick of good" unless you keep them properly maintained and serviced.

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Part 107: The Toddler in the FARs

RAINBOW Aviation Services™

The new 14 CFR Part 107 regulation governs small unmanned aircraft systems (sUAS) or drones. A UAS by definition is an aircraft without a human pilot onboard and is controlled by an operator on the ground. Part 107 is one of the youngest regulations within the FARs. In preparation for this article we contacted the FAA's UAS division. We had a bit of an advantage, since Earl Lawrence, Director of the Office of Unmanned Aircraft Systems Integration for the FAA, is a longtime friend and colleague. Many of you reading this article may also know Earl Lawrence personally. Earl was VP of Industry & Regulatory Affairs for EAA before he moved to the FAA, (or as we affectionately call it, the "Dark Side") in 2010. Earl arranged for us to have a meeting with David Russell. David is a Management and Program Analyst for the UAS Integration Office and he offered some real insight into this entirely new division within the FAA. One of the most interesting analogies, which David eluded to, was a comparison of drone technology today having a direct correlation of what it must've been like during the early days of automobiles. In the early days of automobiles there were literally thousands of individuals, carriage manufacturers, and bicycle shops suddenly having access to a small internal combustion engine. Entrepreneurs adapting these engines, via a chain to their existing vehicles, were now part of the new automobile industry. David indicated, just like the early days of the automobile boom, estimates are, that there are currently over 2000 different drone manufacturers around the world. There are many other parallels as well. In the early days of the automobile, the roadway infrastructure was very limited. There were no roadsigns. Rules about how to operate these vehicles was limited and often times different from

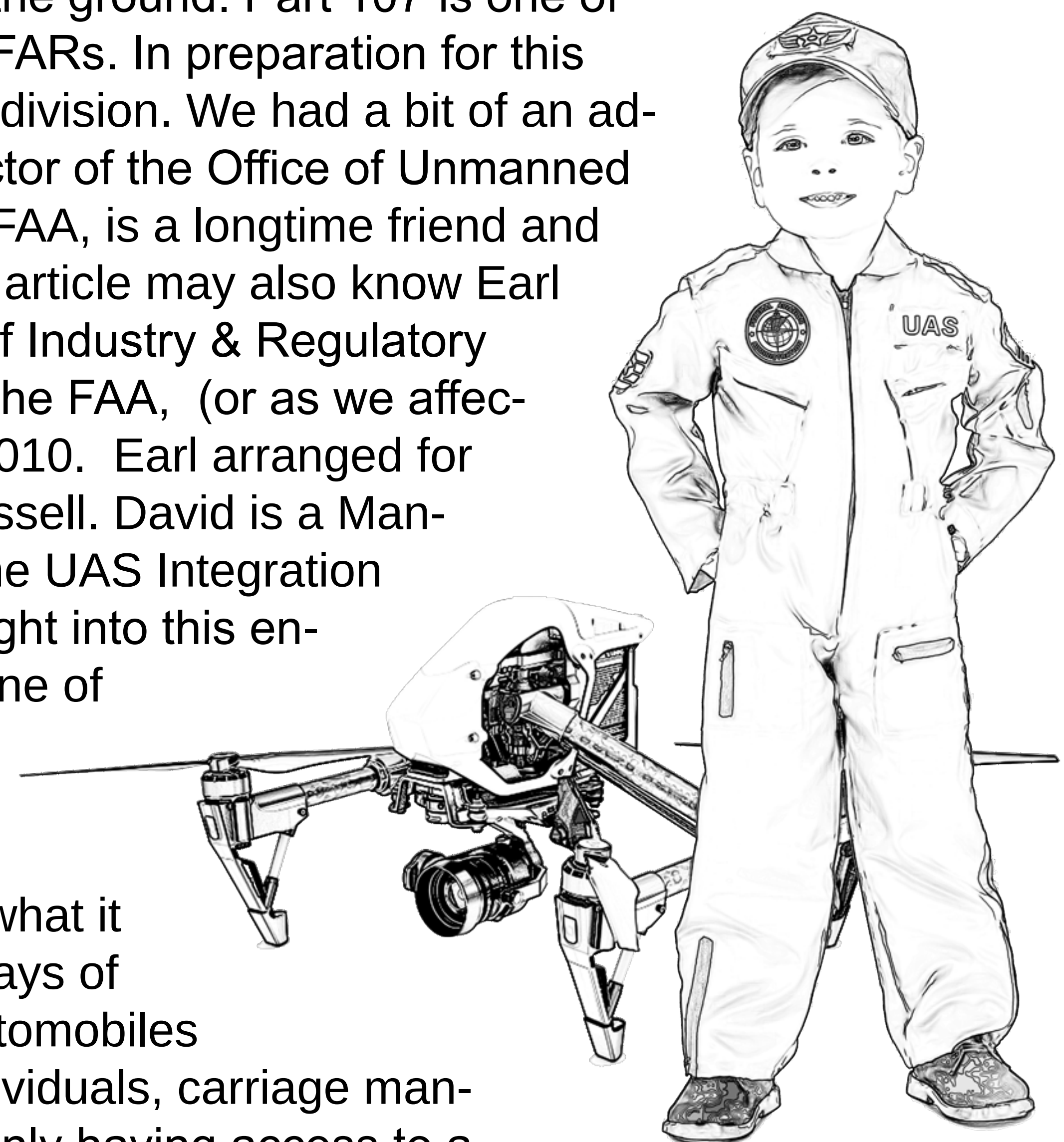

Figure: 1 Remote Pilot Certificate

state to state. There were no books on how to operate these vehicles. There was no standardization for parts or even tools to work on these vehicles. Can you imagine? That's the daunting task of the UAS division currently. The technology is changing so quickly that it's very hard to predict where this technology will lead. Writing rules to protect the general public while simultaneously allowing for the entrepreneurial spirit to flourish, requires a very delicate balancing act. But like the automobile industry, this new technology promises to be a very integral part of the future. Let's take a look at some definitions and regulations to bring you up to speed with where we are today.

You don't need permission from the FAA to fly your UAS (aka drone) for fun or recreation, but you must always fly safely. Before you fly outside you must: Register your UAS if it weighs more than 0.55 pounds and less than 55 pounds, Label your UAS with your registration number, and read and understand all safety guidelines. To register a drone you must be at least 13 years of age or older and be a U.S. citizen

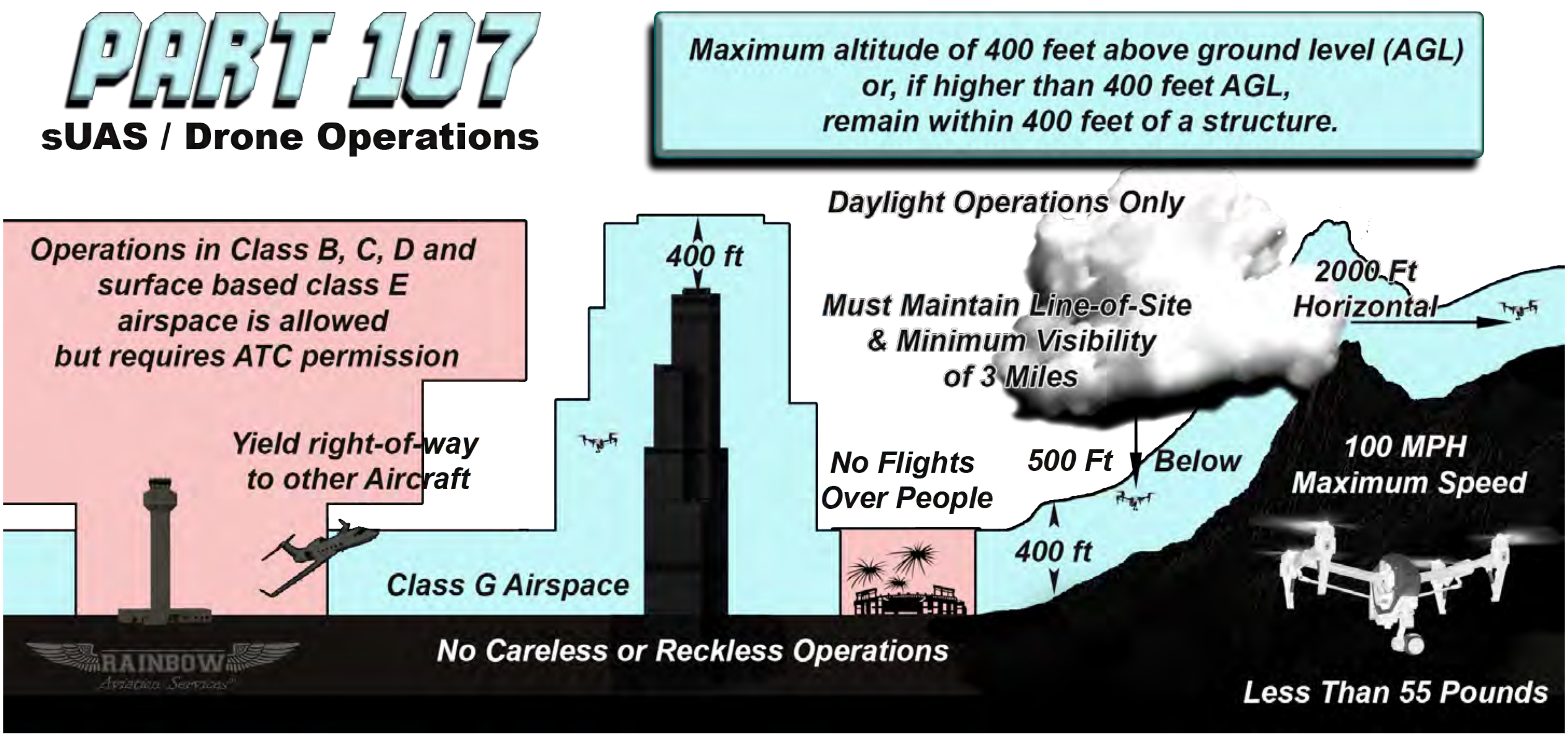

Figure: 2 Part 107 Drone Airspace and Operating Rules

or legal permanent resident. All in all, this isn't too onerous for the average hobbyist. However, I'm constantly surprised how many drone owners are unaware of the registration requirements. The FAA could definitely use your help in getting the word out. Keep in mind, you could be subject to civil and criminal penalties if you meet the criteria to register and do not register, including fines of up to $250,000. The good news is, the registration process is really quite simple and it only costs $5. (https://registermyuas.faa.gov/).

A person operating a small UAS commercially has an entirely different set of requirements. They must either hold a remote pilot airman certificate with a small UAS rating or be under the direct supervision of a person who does hold a remote pilot certificate.(Figure: 1) If you hold a pilot certificate (not a student pilot certificate) and your flight review is up-to-date, the process of obtaining a remote pilot certificate is relatively simple. All you need to do is complete the sUAS online training course available at the FAA Safety Website and the required the application.

If you do not hold a pilot certificate, you will need to be at least 16 years old to start the process. Then pass an initial aeronautical knowledge test at an FAA approved testing center. In addition, you will also be required to be vetted by the Transportation Safety Administration (TSA). Then you will also need to completed the FAA application using the electronic FAA Integrated Airman Certificate and/or Rating Application system (IACRA).

As far as operations of the aircraft are concerned let's summarize the key rules. The maximum weight of your drone must be less than 55 lbs. You must maintain visual line-of-sight with the drone at all times, and yes the FAA has come up with a new acronym for that (VLOS). Safety is the key element of all of the new rules, so no flying over other persons. Daylight operations only. You must yield the right-of-way to other aircraft. No careless or reckless operations. No carriage of hazardous materials. No operations from a moving aircraft and no operations from a moving vehicle unless the operation is over a sparsely populated area. External load operations are allowed if the object being carried by the unmanned aircraft is securely attached and does not adversely affect the flight characteristics or controllability of the aircraft. If you want to lose someone in an article, the best way to do that is start quoting regulations. So in order to keep you from falling asleep we generated a graphic to summarize the majority of rules regarding drone flight within different airspace. (Figure: 2) The rules as a whole, make a lot of sense. And if you're concerned about anyone of the restrictions, there is an entire-

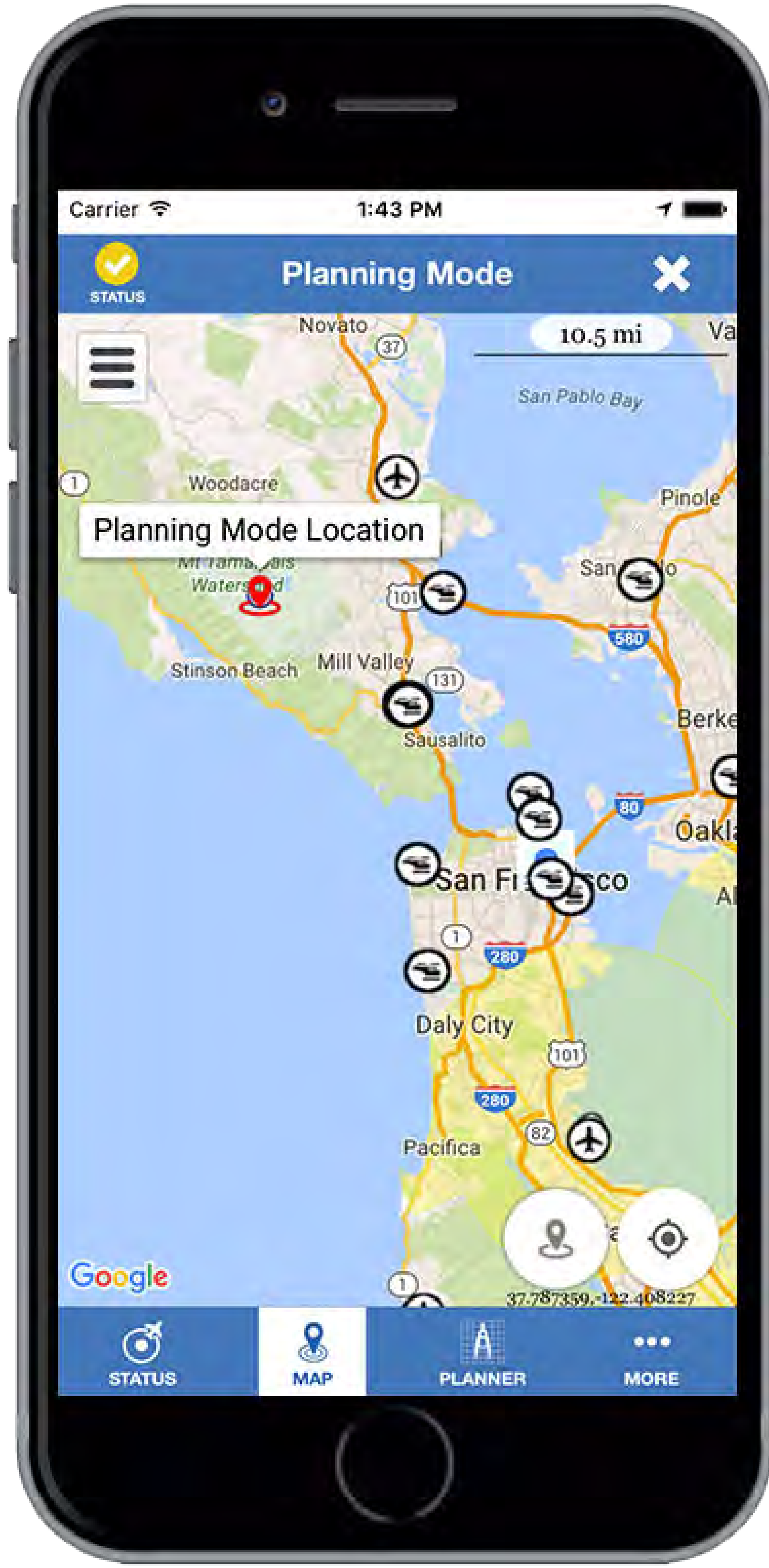

Figure: 3 B4UFLY App

ly separate system in place for obtaining a waiver for most operations, this providing that you can show that the proposed operations can be conducted safely. Temporary Flight Restrictions (TFR's) is another area that we continue to see airspace violations. TFR's, by definition, are very dynamic. These typically pop up unannounced as a result of forest fires, chemical spill, and political or sporting events. In California we have had several instances, during fire season, where the entire aerial firefighting operation came to a halt as a result of a drone operating in the same airspace as the air tankers. In these cases, there is normally a heavy fine associated with the airspace incursion. If you spot a forest fire, you can bet your bottom dollar there's going to be a TFR issued very shortly. The rule of thumb for all of us general aviation pilots is simply stay away. The FAA has come up with a new easy-to-use smartphone app called B4UFLY. This app helps unmanned aircraft operators determine whether there are any restrictions or requirements in effect at the location where they want to fly. Some of the key features of the B4UFLY app include: A "status" indicator that immediately informs the operator about the current or planned location. For example, it shows flying in the Special Flight Rules Area around Washington, D.C. is prohibited and contains Information about any restrictions. There is also a "Planner Mode" for planning future flights in different locations. Lots of Informative, interactive maps with filtering options.(Figure: 3) This is the go-to app if you're a drone operator. The rules that the FAA has come up with seem very reasonable. And as we indicated, Part 107 is continuing to evolve. It is incumbent upon all of us who operate drones, that we conduct these operations safely. Not only safely, but smartly. There is still a significant amount of skepticism from the general public as well as other pilots about their willingness to accept drones within the national airspace system. Many times perception and public opinion can be the villain that causes the FAA to have to write more restrictive rules. Although it may not be illegal to fly over your neighbor's property, doing so without their permission oftentimes makes them feel intruded upon and unsupportive of your freedoms. If you're going to fly drones we strongly recommend that you follow the existing rules and set the example for others to follow by being a good neighbor. The future of drones is extremely bright and the potential for this revolutionizing aviation is truly at hand. Virtually, the only thing that can slow down the frenetic pace of technological innovation and growth within this industry will be more restrictive regulations.

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For decades now, we have been advocating for an engine replacement scenario that has garnered significantly reduced operating costs. We call this scenario the Rainbow Aviation Formula (RAS formula).

This all started some 25 years ago while discussing maintenance philosophy with one of our more well-to-do customers. The topic was centered around the subject of how to maintain reliability as the hours on his engine began to accumulate. What came out of this discussion was an experiment that continues to this day with extraordinary and surprising results.

The premise of this construct is based on the principles that a new engine with low hours is going to be more reliable than an old engine with high time. Fig.1 When an engine is new the amount of maintenance necessary is limited to simple things like oil and filter changes. However, as an engine ages, we get into that area where we start having to accomplish major tasks on items like cylinders, carburetors, magneto's,

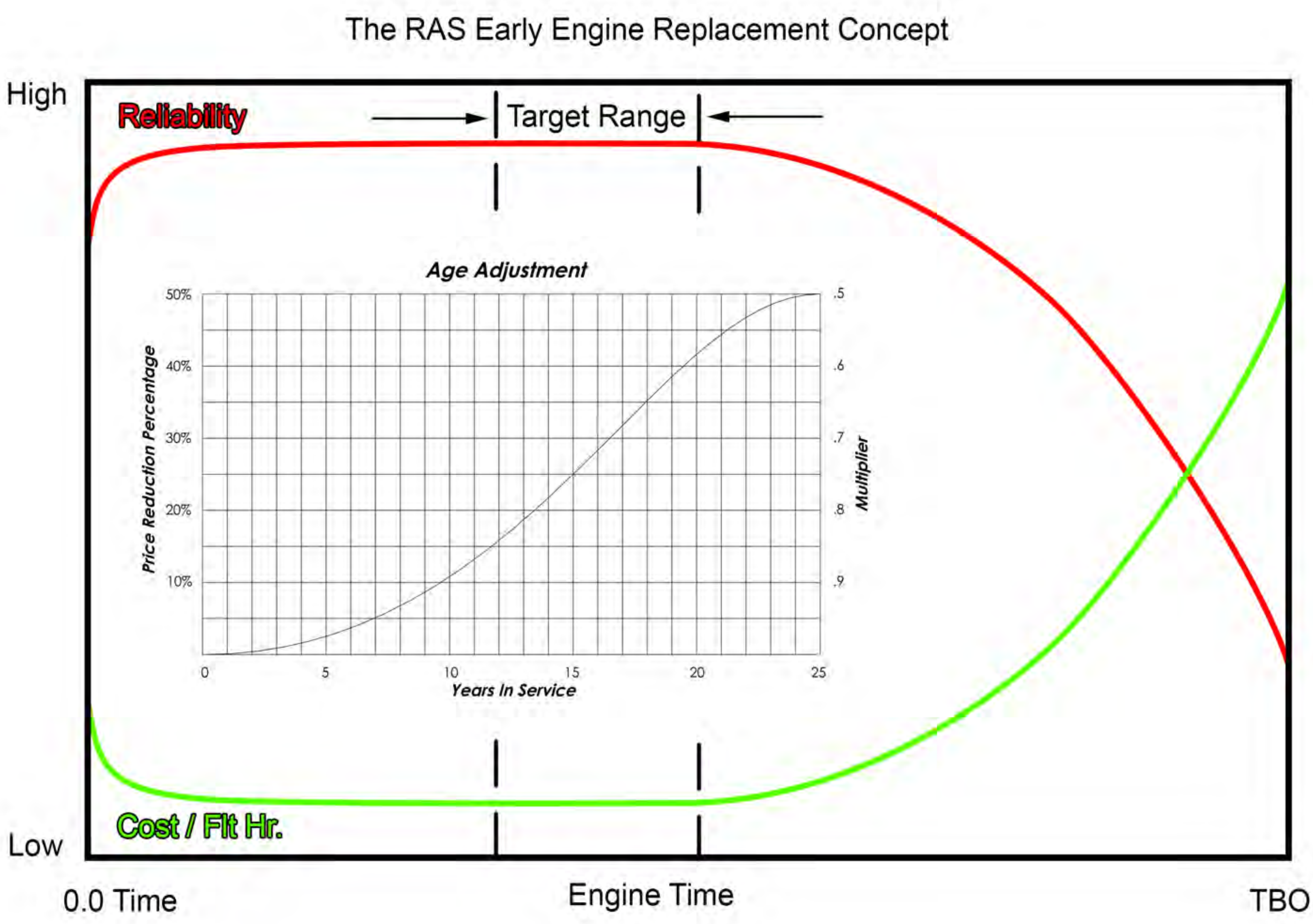

Figure: 1 The RAS Early Engine Replacement Concept gearboxes, starters, and exhaust systems. These tasks can involve thousands of dollars. And even the little items like spark plugs, hoses, and wiring can nickel and dime an owner to death.

After many years of working with specific customers utilizing our formula and tracking their maintenance costs. We have been able to come up with comparisons to the traditional maintenance paradigm where customers operate their aircraft until the engine is no longer economically viable to repair. The results were not only obvious, but shocking. One customer was so impressed by the results, he had us replace his Lycoming O-360 on his Cessna 172 (with a Penn Yan Conversion), 6 times over a period of 10 years. This customer flew a considerable amount of cross-country, night, and IFR flight, and really appreciated having a factory new Lycoming engine installed every couple of years. Initially, not for the cost savings, but rather for the sense of confidence that went along with that new "bulletproof" Lycoming engine. After seeing the financial rewards of early engine replacement, the choice for him was a no-brainer.

So, let's look at how this process would normally play out. We would typically wait until the O-360 engine would have around 800 hours on it and then advertise it for sale utilizing our formula. Fig 2 Now, the key to this working successfully, is to leave the engine on the airframe. Remember, any engine removed from an airframe

RAS EARLY ENGINE REPLACEMENT FORMULA

$$\frac{\text{New Engine Cost}}{\text{TBO}} = \text{Basic Cost per Flight Hour}$$

(Engine Time) X (Basic Cost Per Flt Hr.) = Value Consumed

(New Engine Cost) - (Value Consumed) x (Age Multiplier) = Sales Price

Figure: 2 RAS Early Engine Replacement Formula

has only a core value. Never remove the engine from the airframe until you have the money in the bank. By leaving the "new" engine installed on the airframe, a prospective customer can come and fly the airplane, "hear" the engine, do compression checks, borescope, oil analysis, and oil filter inspection. Basically, do anything to feel 100% confident that the engine is in excellent condition before deciding to buy. The hallmark of any good negotiation is finding a "win-win" scenario. And the goal here, is to make both parties happy with the decision to purchase an 800 hour engine.

Let's be clear. We are using the engine for the timeframe of high reliability and low operating cost and then selling the engine to avoid the high operating cost and low reliability. So, why in the world would anyone want to buy "this" engine. Think about "our" demographic. And when we say "our" demographic, we are talking about the experimental aircraft crowd. The group of people who love building and flying, but whose budget is often limited. To the builder on a budget, the thought of a 2 year old, factory new, Lycoming engine, with 800 hours on it, is a godsend and a no-brainer. No one has been inside the engine screwing it up. It's going to be reliable. And the best part is, it's a fraction of the cost of a new engine. In our experience, there are far more people wanting to buy these engines than there are people wanting to sell them. The experimental aircraft builder is perfectly suited for dealing with these higher time engines primarily because they can do the work themselves.

The interesting part is that once you get over the hump of purchasing the first engine, and getting rid of it in the "target range", the cost of the next new engine is subsidized by the sales of the first engine. You will soon see that the actual cost per flight hour will diminish to the point that you can pay the cost of the new engine installation and then some. The fact that you will always get to operate a new engine, with its subsequent reliability, is the icing on the cake that really makes this a valuable exercise. Think of it as having the perpetual reliability of a new engine without additional cost.

There is virtually no cost to this early engine replacement concept. Put an ad on barnstormers. If no one is interested in your engine you simply keep flying your airplane. Your airplane is not out of service. You can continue to fly. And if no one ever bought the engine, it would be no different than before you place the ad. As you accumulate hours, the formula still holds true. As the engine accumulates time, the price is reduced per the formula until we hit the "core" value of the engine.

The "target range": This is somewhat subjective, and every engine is a bit different. We have our own target range for each engine based on experience. The goal is to get rid of the engine before any significant maintenance may be required, while simultaneously identifying the sweet spot for selling. Selling the engine too early doesn't amortize the cost of the engine removal and new engine installation. In addition, there isn't enough depreciation in the engine to make it tantalizing for the buyer. Waiting too long to sell the engine has a psychological effect on the purchaser. Not enough hours left on the engine to leverage the concept. And too many unknowns. You can tell if you have waited too long and or have too many hours on the engine because the number of interested buyers drops dramatically. And although we have identified our target range for the Lycoming O-360 of around 800 hours for this article, we are reluctant to willy-nilly identify the target range for other engines. Many of these engine manufacturers find our analysis contrary to their desired reputation, and as a result, we attempt to keep from ruffling too many proverbial feathers. This being said, an engine like the O-360 is a very easy engine to sell because of its wide variety of suitability in different experimental aircraft. You may find that some engine models because of their low sales volume or applicability to experimental aircraft have a much more difficult time taking advantage of our early engine replacement concept. But even with weird engines, the cost to advertise is negligible. And, as a result, what have you got to lose. Also, keep in mind we use this formula almost exclusively when talking about the purchase of a factory new engine. The ability to translate this formula and concept to an overhauled engine is not nearly as reliable. The high degree of variability from one overhaul shop to another makes it an unreliable premise.

If you're unsure about this, look around and you will find many correlations with other commerce. This is the same concept that the rental car companies use. By renting new cars, the necessity for heavy maintenance is virtually eliminated. The satisfaction of the customer goes way up when you ensure reliability. And having a product with a manufacturer warranty significantly reduces the risk and liability. As the car ages and approaches the limitations of the warranty, the rental car companies sell off the old inventory and replace it with new. It simply makes economic sense. Oh, we're sorry, were you under the impression that the rental car companies love you so much they just wanted to make sure that you had a nice new car every time that you showed up? Awww, to be naïve again. All joking aside, it really is a premise that makes economic and logical sense from so many different standpoints.

Now, we realize this isn't going to be for everyone. And it certainly doesn't have to be. It works best when we are using modern consumer type aircraft engines with a relatively high turnover or sales volume rather than experimental engines. And having an airplane that we put a considerable amount of time on each year seems to work better than engines that sit year after year. We have put together dozens of deals for customers using our formula. The formula doesn't have to be cast in stone, but over years of doing this, we found that it's pretty fair for both parties involved. We have used the formula for Continentals, Lycomings, and all of the Rotax engines, both the 912, as well as the 2 stroke engines.

It's fun to put together these kinds of deals, because in these cases, both parties are pretty excited about the possibilities. One owner gets to fly behind a brand-new engine, and the other can now afford that engine to complete his new handcrafted flying machine. It's hard to think of a more natural symbiotic relationship for the experimental aircraft world.

In between each LSRM (Light Sport Repairman Maintenance) class, we usually spend a considerable amount of time upgrading our curriculum. For some time now, we have had a desire to rewrite the curriculum surrounding the fuel pumps used on the Rotax 912. For many years the fuel pump issue was a hot topic in class. There had been a significant number of problems related to the mechanical fuel pumps. Many of the problems were created by the operators, but a few were obviously related to the design of the fuel pump. As a result, around 2013, Rotax issued service bulletin SB-912-063 (Replacement of fuel pumps). This began the introduction of the 3rd generation of fuel pumps, (part numbers 893114, and 893115). (Figure: 1) It's good to report, that in the five years since their introduction, their performance and reliability has been much better than the predecessor 2nd generation fuel pumps P/Ns (part numbers 892542 and 892546). These pumps can be readily identified at a glance by the distinctive "AC" stamped into the top of the fuel pump. (Figure: 2) But more specifically by the part number engraved onto the base of the fuel pump mounting flange. (Figure: 3) If you're wondering about the difference between the two part numbers, it's simply the same fuel pump, one with hoses pre-installed and the other without.

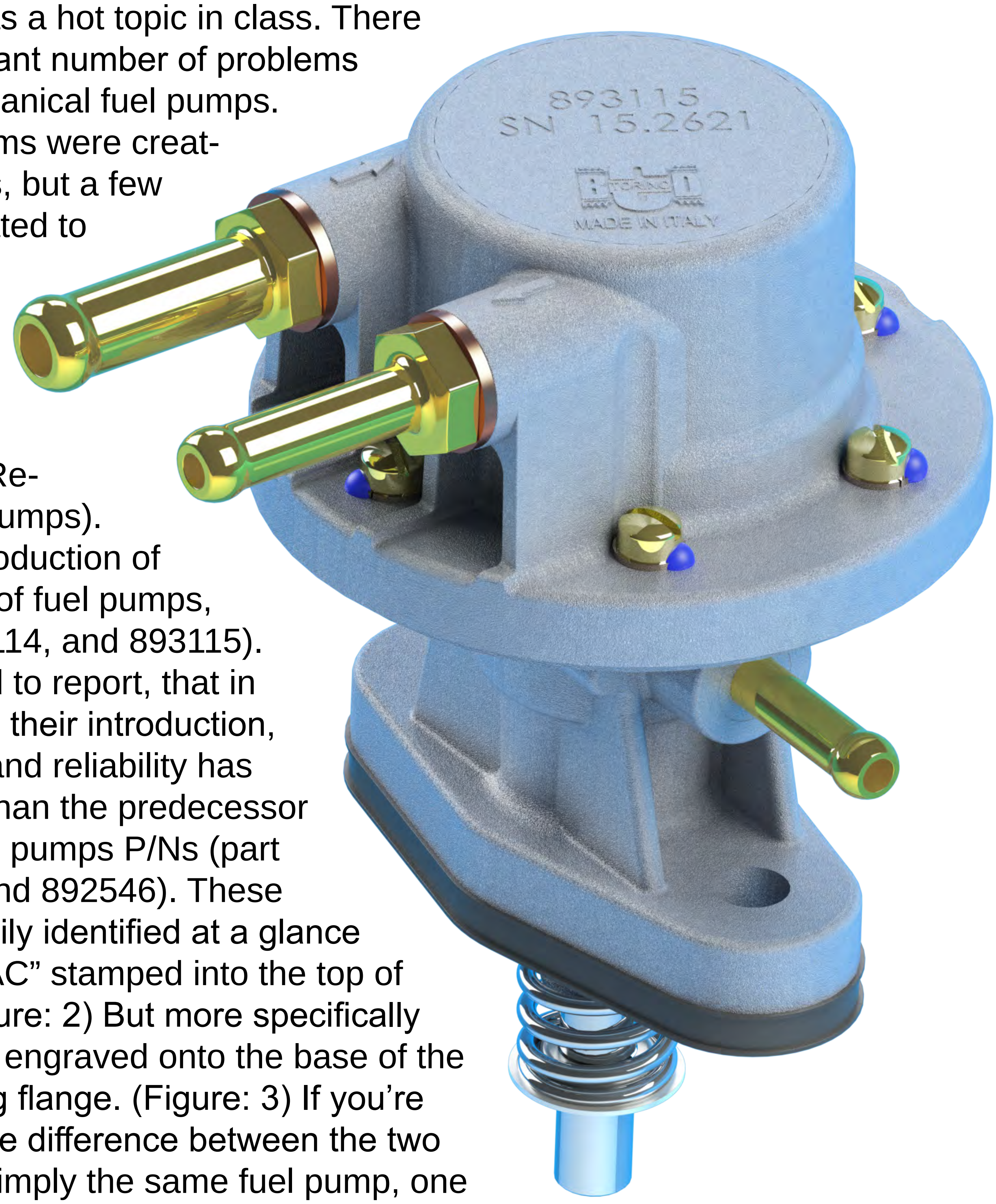

Figure: 1 Fuel Pump Rendering

Accurately and completely generating a 3D model allows us to showcase the internal workings of the fuel pump with cutaways, transparencies, drawings, exploded views, and renderings that are unsurpassed in conveying concepts in the classroom. The only way to get a truly accurate 3D model of the fuel pump is to disassemble a pump for reverse engineering. This is a completely destructive process requiring cutting into

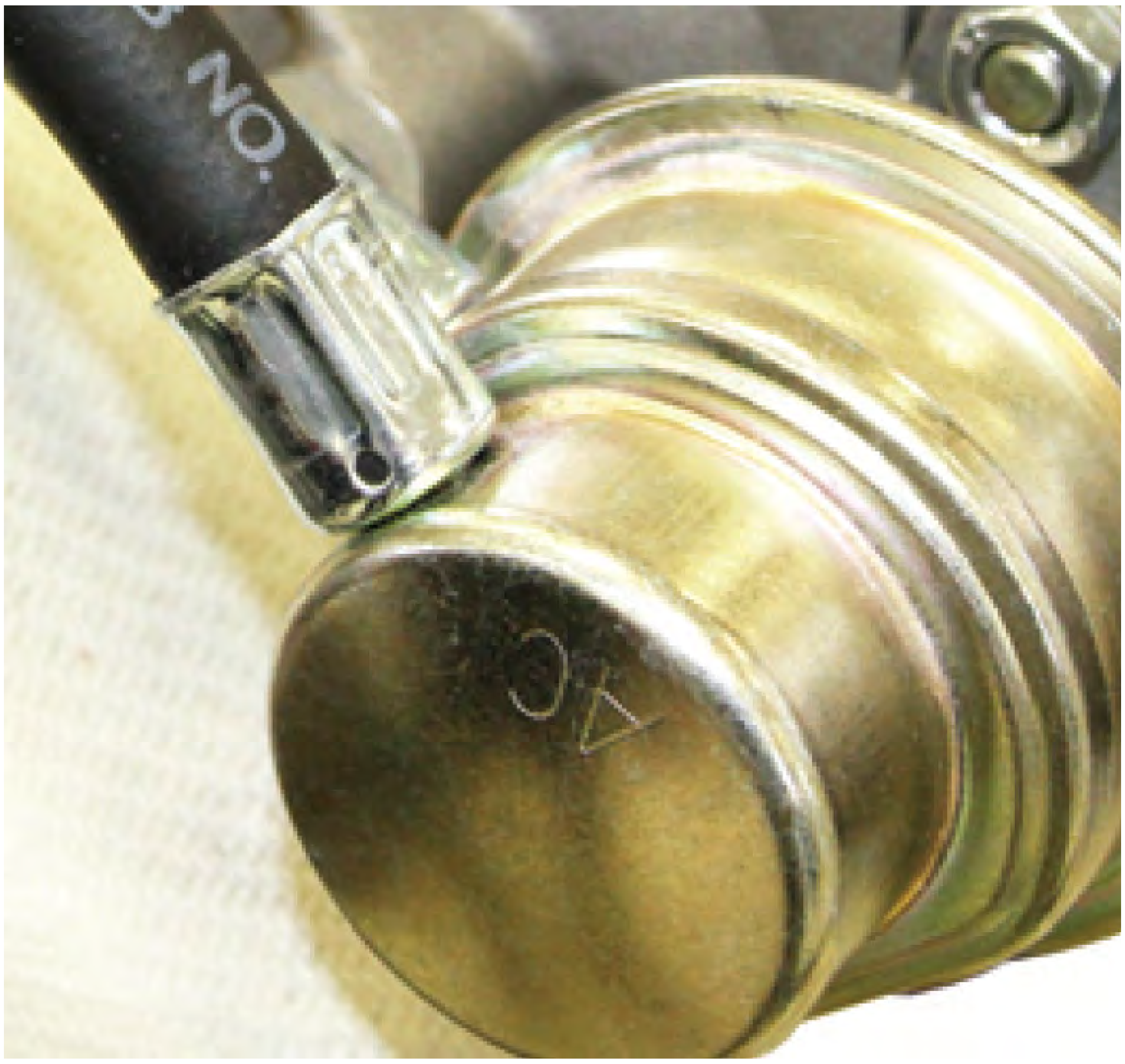

Figure: 2 2nd Generation Fuel Pump

many of the components to obtain accurate dimensions, especially on enclosed parts. It's hard to get excited about cutting into a brand-new $200 fuel pump, destroying its usefulness, simply for the privilege of measuring each component. However, fortune smiled upon us, when our request for a damaged fuel pump was fulfilled by one of our former students. And although the 3D model and associated renderings for this article are primarily about the new fuel pump, it is always fun to showcase the capabilities of Solidworks 3D modeling software which is available free to EAA members.

Now that we can "see" inside of the fuel pump, we can get a better understanding of how it works. Overall, the basic operation is similar to that of almost all mechanical fuel pumps being manufactured. The conceptual technology of a diaphragm and two check valves to move a fluid has been around for hundreds of years. When it comes to aircraft, the trick is, making it reasonably priced, lightweight, and most importantly, safe and reliable. The challenge here, is obvious considering we are now working on generation three of fuel pumps for the Rotax 912. (Figure: 4) shows the internal components that make up the fuel pump. The base of the fuel pump is attached onto the gearbox housing and the pump shaft is actuated by an eccentric cam attached concentrically to the propeller shaft. A heavy spring, (with a force of approximately 50 pounds per inch travel) is located at the base of the fuel pump housing and is attached to the fuel pump shaft with a "cup" washer and retaining clip. This essentially holds the pump shaft against the eccentric cam on the prop shaft. This is where we find some of the greatest misconceptions regarding the operation of the fuel pump. The other end of the pump shaft is not directly connected to the diaphragm, but rather, free floats inside of a "bell housing" which <u>is</u> directly connected

Figure: 3 P/N Identification

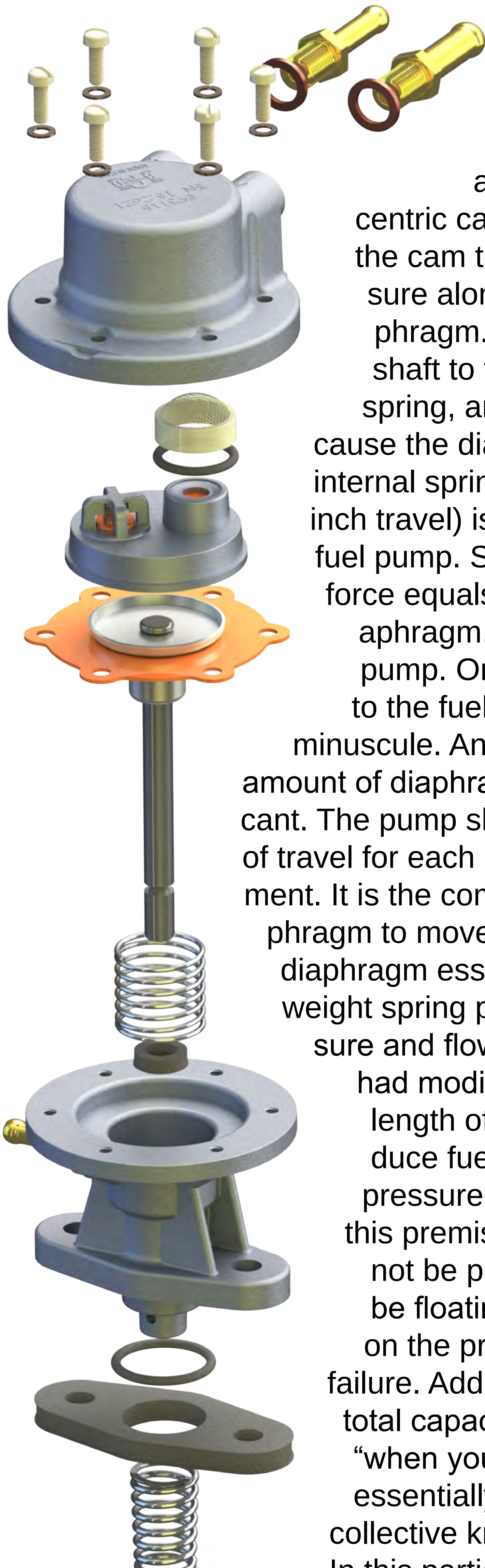

Figure: 4 Exploded View

to the diaphragm. (Figure: 5) The shaft makes contact with the lower portion of the bell housing and can pull down on the diaphragm, but "free" floats into the bell housing as the shaft is actuated into the pump by the eccentric cam on the prop shaft. Since it is not possible for the cam to pull on the pump shaft, it is the spring pressure alone that creates the force to pull down on the diaphragm. And since there is no connection from the pump shaft to the diaphragm on the upstroke, it is the internal spring, and only the pressure from that spring that can cause the diaphragm to move in the upward direction. This internal spring (with a force of approximately 22 pounds per inch travel) is by default what controls the pressure on the fuel pump. Surface area of the diaphragm divided by spring force equals fuel pressure. The only movement of the diaphragm, is, a result of the fuel moving through the fuel pump. On engines at idle and without a fuel bypass back to the fuel tank, the amount of diaphragm movement is minuscule. And at full throttle with a built-in fuel bypass the amount of diaphragm movement is going to be much more significant. The pump shaft on the other hand, has the identical amount of travel for each revolution, irrespective of diaphragm movement. It is the combination of the two springs that cause the diaphragm to move. The heavier external spring pulls down on the diaphragm essentially priming the pump. In the internal lighter weight spring pushes up on the diaphragm causing fuel pressure and flow. We have recently talked to a mechanic that had modified dozens of fuel pumps by cutting down the length of the external spring thinking that this would reduce fuel pressure. Although you "can" reduce the fuel pressure this way, he had missed the bigger picture. For this premise to work, the external spring would essentially not be priming the pump as much. The pump shaft would be floating and bouncing on and off of the eccentric cam on the prop shaft creating the potential for premature failure. Additionally, this would be, essentially, reducing the total capacity of the fuel pump. We often say in class that "when you find yourself modifying a component you are essentially claiming that you are smarter than all of the collective knowledge of the engineers at the Rotax factory". In this particular case, the mechanic was trying to solve a symptom of a bigger problem. He was attempting to remedy a needle and seat leaking problem that he, ironically, had created by another misunderstanding of the basic physics involved in that system.

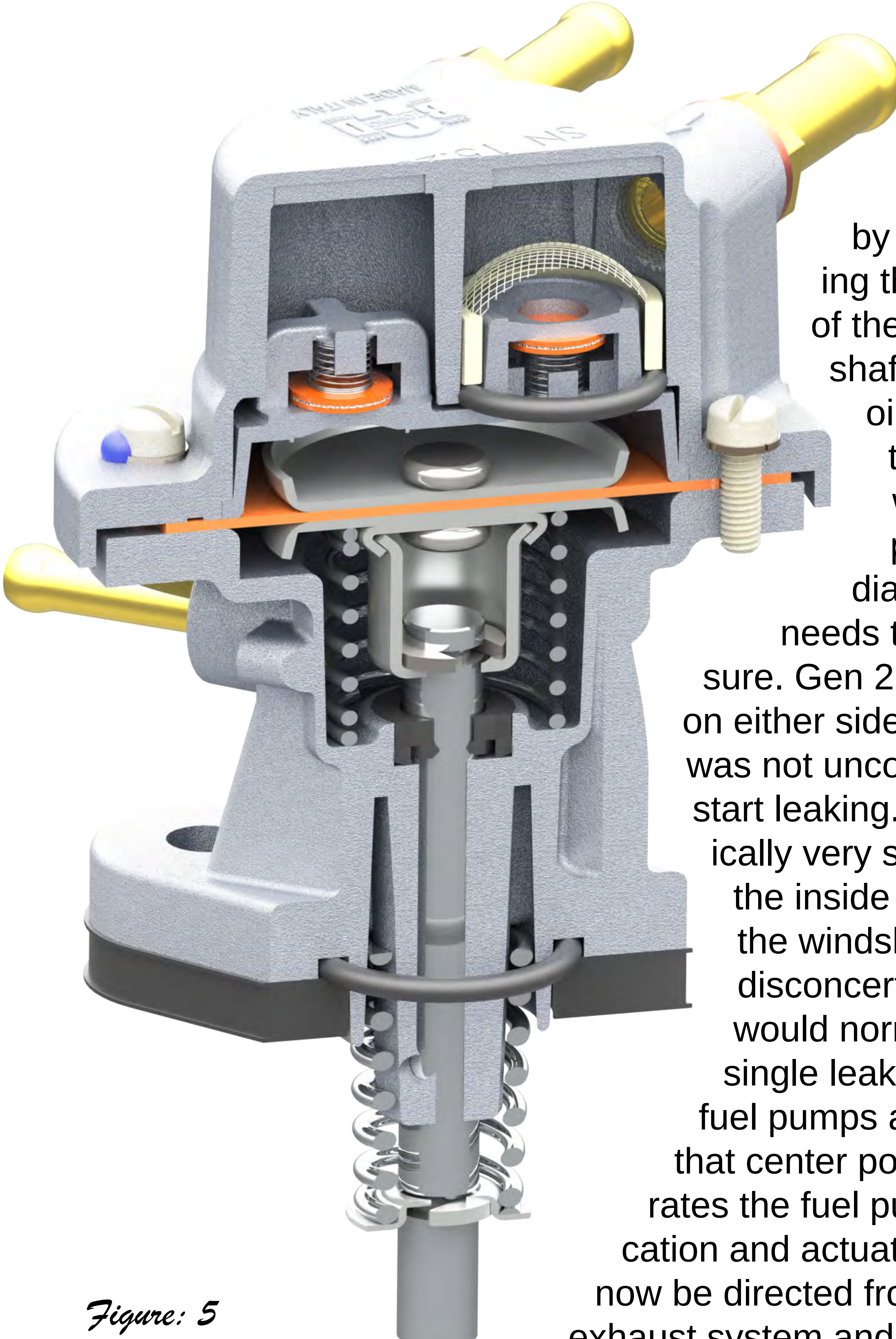

Figure: 5
Cut-Away View

The pump shaft is lubricated by two slots cut into the lower housing that run either side of the length of the bearing surface for the pump shaft. A “Garlock” type seal prevents oil from leaking into the center of the pump. This is one of the areas where the 2nd generation “AC” pumps suffered problems. For the diaphragm to move, the underside needs to be vented to atmospheric pressure. Gen 2 pumps have two small vent holes on either side of the lower pump housing. It was not uncommon for the Garlock seal to start leaking. And although the leaks were typically very small, having that oil blown around the inside of the cowling and typically onto the windshield and fuselage was rather disconcerting on an engine that otherwise would normally make it to TBO without a single leak. On the new style 3rd generation fuel pumps a drain nipple is incorporated into that center portion of the fuel pump that separates the fuel pumping section from the oil lubrication and actuation section. (Figure: 6) A line can now be directed from the fuel pump down past the exhaust system and out the belly of the aircraft. Oil coming out of this line indicates a Garlock seal failure. Fuel coming out of this line indicates a fuel diaphragm failure. As you might imagine, having fuel or oil for that matter dumping directly into the engine compartment isn’t ideal. However, the purpose of this vent hole was two-fold. It supplied additional information about the condition of both the Garlock seal and the pumping diaphragm. Many builders are now incorporating a small (vented) collecting bottle at the end of this vent line to capture any leakage for inspection and evaluation purposes. Theoretically, locating the vent line in a higher or lower pressure area would act as an additional force on the pumping spring changing fuel pressure.

The dual check valve subassembly is very traditional. Consisting of two fabric reinforced silicone pads that act as check valves backed up by very small springs. These allow flow of fuel in one direction only. And the springs are lightweight enough to easily allow flow of fuel from an electric boost pump to flow freely through the pump. The inlet and outlet side of the pump can be identified by the arrows embossed on the top of the fitting bosses. In addition, the inlet fitting is larger diameter than the outlet fitting. As the diaphragm is pulled down by the lower external spring, the fuel is drawn in through the inlet fitting and into the inlet chamber where there is a flexible plastic filter (approximately 400 micron) that protects the check valves against contamination. Even a small piece of contaminant can get under the face of the check valve disabling its function, and as a result, it is a critical component in the fuel pumps operation. Gen 2 pumps also contain an internal filter, but it is located where it is impossible to inspect or clean. Let's be clear, all three generations of fuel pumps are considered non-repairable. Even the new generation pumps have screws around the perimeter which will allow you access to the diaphragm and the pump shaft seal, but they are still considered non-repairable. Each of the screws has "torque seal" applied at the factory. Disturbing the torque seal by removing the screws voids the warranty on the pump. In reality, there isn't any reason to be opening the pump in the first place. The primary function of the pump is the check valves, and these components are pressed into the check valves housing subassembly. Even the housing that holds the check valves in place is pressed into the top of the fuel pump. It required that we drill a hole through the top of the fuel pump and use a punch to extract the check valve subassembly for 3D modeling. This is the component that would have to be removed to have access to the plastic fuel filter. However, unlike the generation 2 pumps, you can get visual access to the fuel filter by

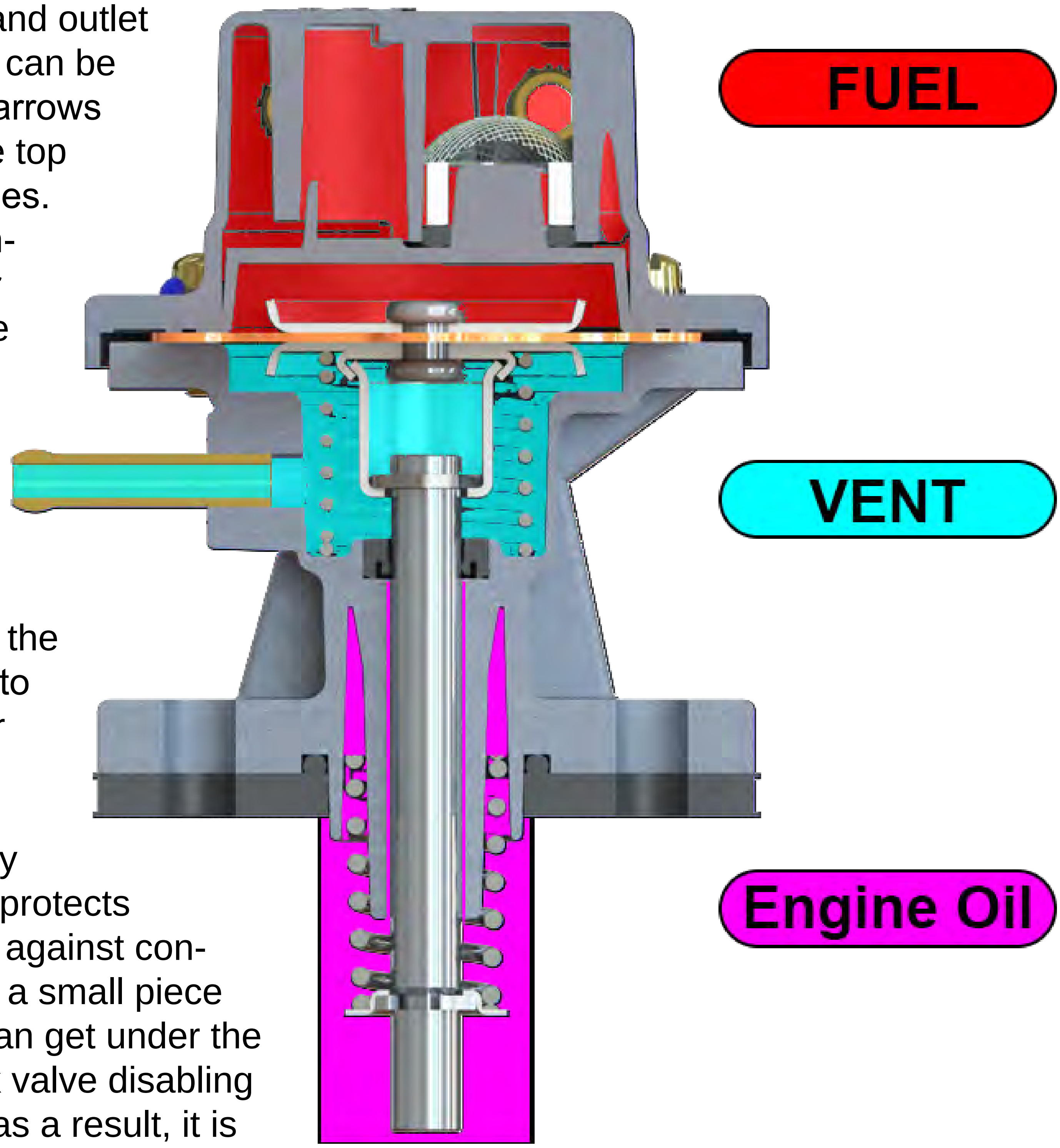

Figure: 6 Fuel Pump Vent

removing the inlet nipple. (Figure: 7) Although, it would still be challenging to clean any contamination from the inlet chamber, having access for troubleshooting purposes is invaluable. Keep in mind that the plastic screen is delicate and fragile. You would never want to use shop air to try and blow through the fuel pump. Blowing backwards through the pump is impossible because of the check valves. And blowing in the normal direction of flow would most certainly damage the plastic filter. Keep in mind, the primary method used in keeping contamination from getting to the fuel pump in the first place is the aircraft or engine fuel filter. Finding contamination in the float bowls of the carburetor, by default, would mean that contamination had to also have also passed through the fuel pump filter.

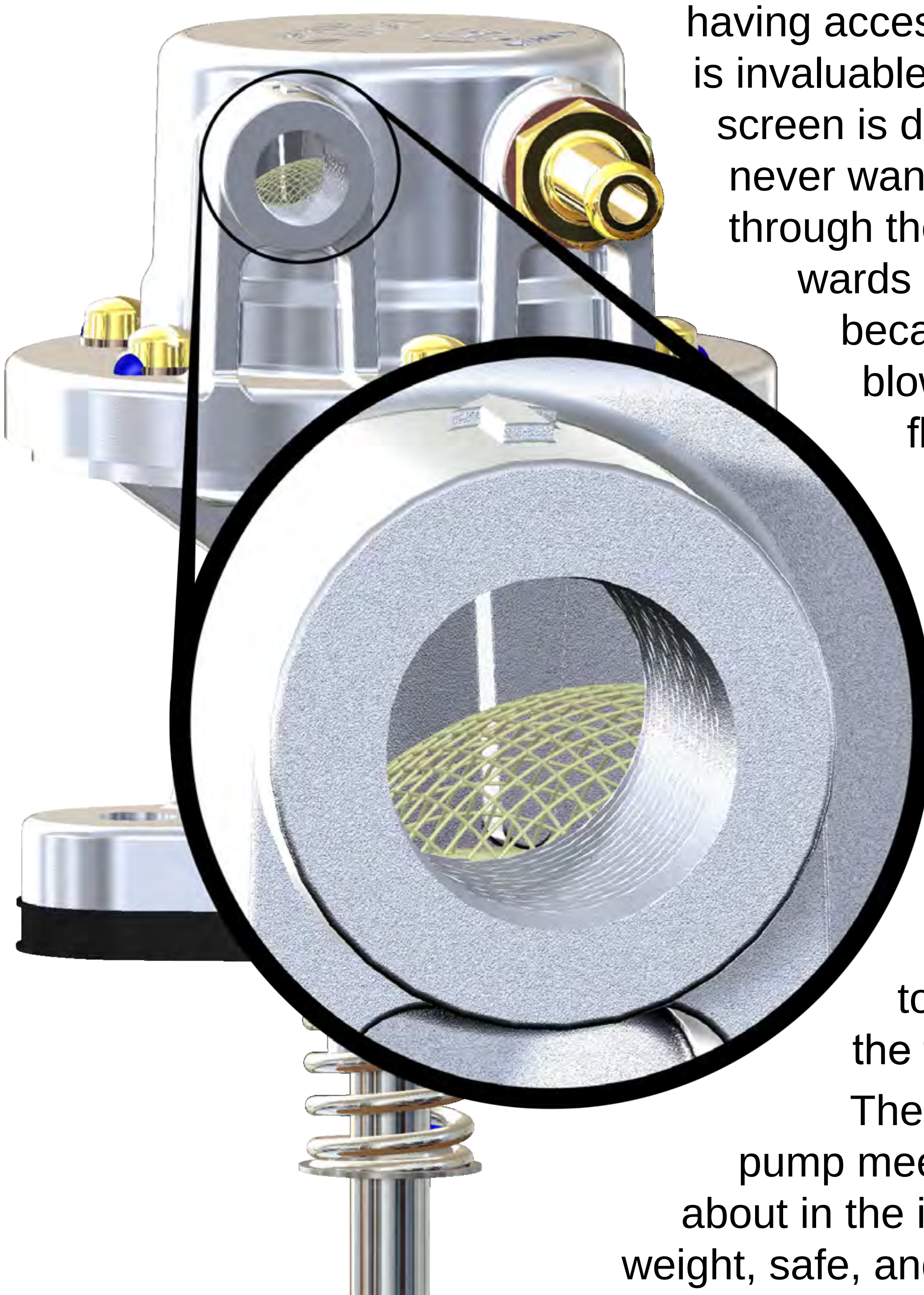

Figure: 7 Filter Inspection

The overall design of this new fuel pump meets all the criteria that we talked about in the introduction, Low cost, lightweight, safe, and reliable. The expectations are that the number of fuel pump related engine problems will be significantly reduced. There will likely continue to be problems created by the operators, but we may have even curbed that problem a bit now that we have undertaken the task of 3D modeling the fuel pump showing the inner workings. Perhaps it will quell that inevitable urge that permeates all aircraft builders: that curiosity to take things apart and see what's going on inside.

Sheetmetal 101: Clecos

Cleco is the trade-name originated from Cleveland Pneumatic Tool Company. The cleco is a temporary fastener primarily used in the construction of sheet metal components. Even though the cleco was a relatively simple tool made up of only a handful of components, (Figure: 1) it revolutionized the sheet-metal aircraft manufacturing process. If you are going to be building a sheet metal aircraft, you undoubtedly will become intimately familiar with the use of the cleco. It is common practice, that during construction, we assemble components of the aircraft and hold them temporarily in place with cleco's as we proceed with the drilling process. After we have laid out and drilled all of the holes in a component, we will need to remove all the cleco's and disassemble the structure so that we may de-burr each of the holes and remove any chips remaining from the drilling process from between the sheet-metal surfaces. Because the dimensions of a structure change with contamination between sheets of metal, it is not uncommon to assemble and disassemble a structure many times before we begin the process of permanently riveting the components together. This is where the cleco really shines. This ingenious tool allows us to assemble and disassemble a structure very quickly. Using a pair of cleco pliers, which grips the body under the manufactured lip, and allows us to actuate the plunger pushing the lock fingers

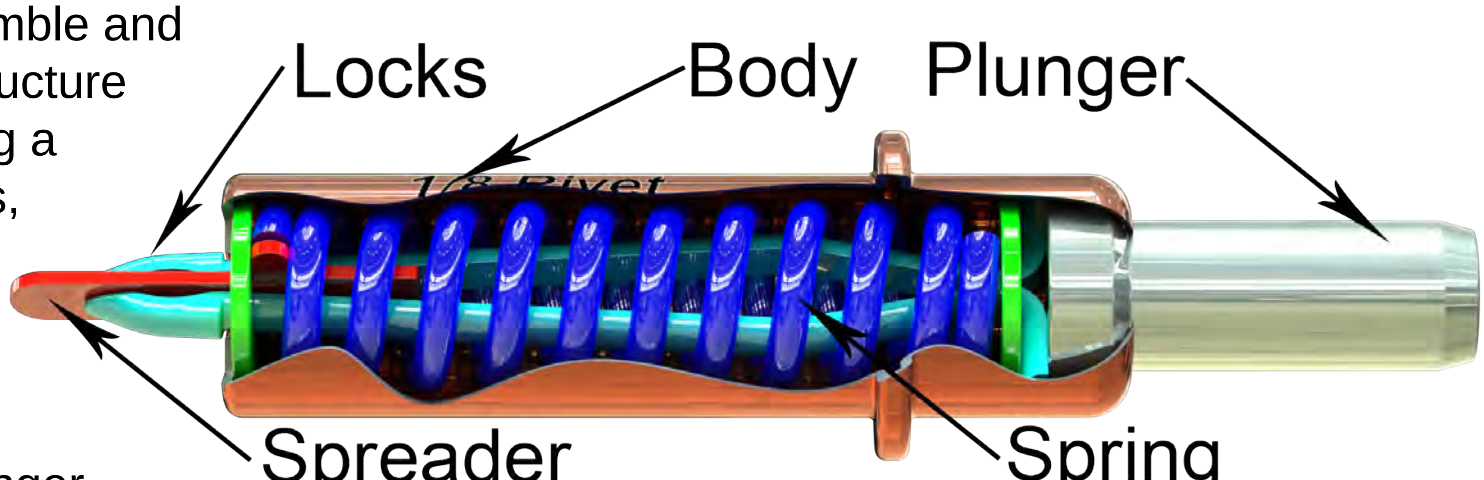

Figure: 1 Components of a Cleco

beyond the spreader bar. this allows the lock fingers to collapse upon themselves making the overall diameter less than the diameter of the rivet hole. This in turn allows us to push the cleco through all of the different layers of sheet-metal. Once the cleco is fully engaged, releasing the cleco pliers allows the fingers to retract and simultaneously be spread out by the "spreader bar" now making the overall diameter of the locks larger than the rivet hole. (Figure: 2) the locks are now under spring pressure holding the individual pieces of sheet metal together .Under normal circumstances,a cleco every 3 to 4 rivet holes may be sufficient. In cases where the sheet-metal consists of multiple layers, and perhaps thicker material, it may be necessary for cleco's in nearly every hole drilled. As the structures get larger and more complex it may be necessary to bring out the "big guns". When we are facing difficulties in pulling all of the different pieces of sheet-metal together tightly we revert to the use of what we call "draw" cleco's. (Figure: 3) These cleco's are much more heavy duty, and rather than using a spring to pull the locks against the sheet-metal, they use a wing nut which can be drawn down with much more force. Often, we are working with casting or machined components that are also attached to sheet-metal structures. The total thickness of material which may be trying to hold together may exceed the capability of a standard cleco. For those special cases we can employ the use of an extra long pull type cleco. The primary drawback to the wing-nut type cleco, is that they are typically quite time-consuming to install and remove compared to their spring-loaded brothers. As a result, they normally only get pulled out of the toolbox when the spring type cleco's just won't get the job done.

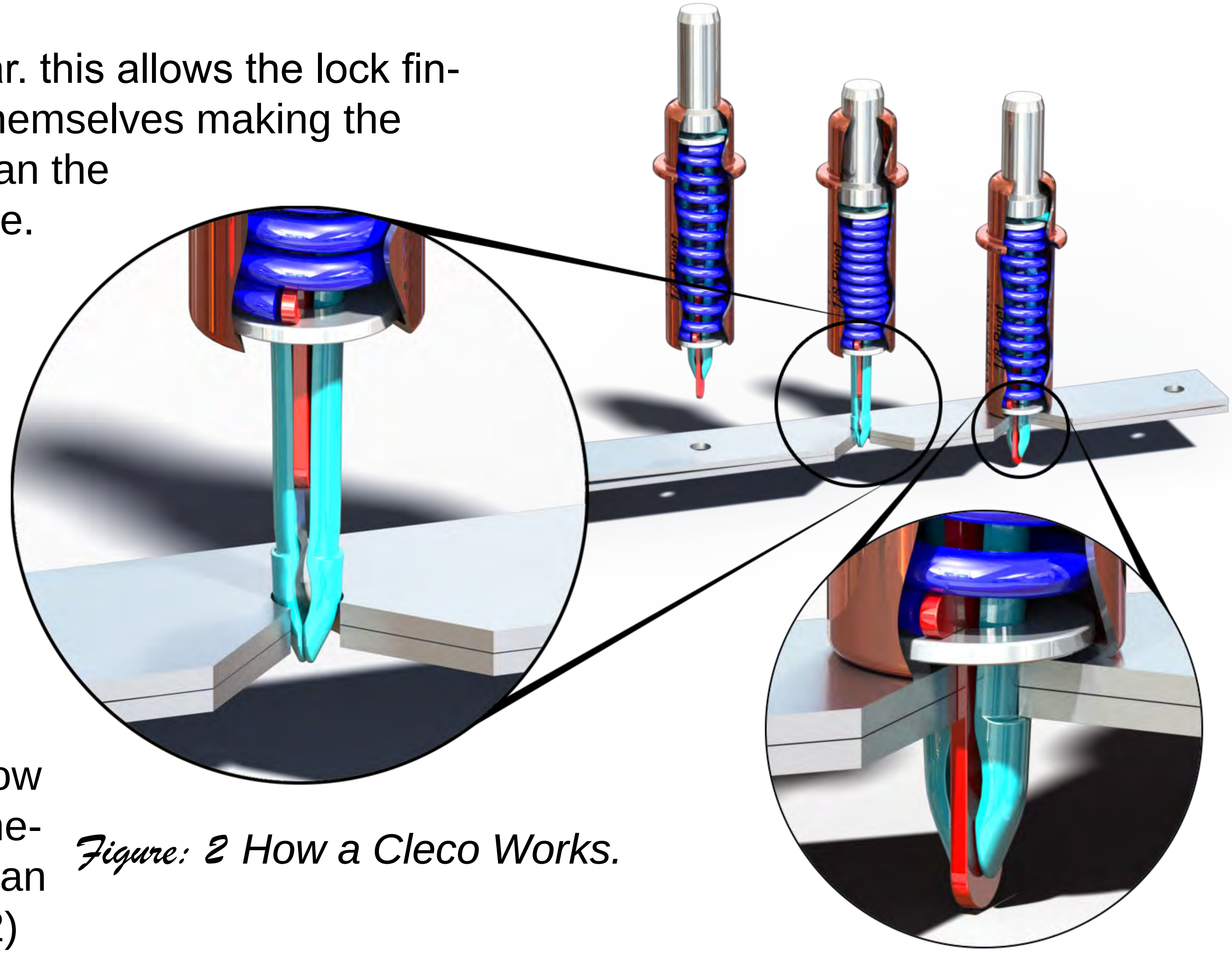

Figure: 2 How a Cleco Works.

When working on sheet-metal projects, we use a variety of different size rivets depending on the type of structure involved. Although the 1/8 inch rivet is probably the most common, we would say that there are four primary sizes used in the majority of aircraft applications. As a result, there are cleco's for each one of the rivet sizes used. Conveniently, the cleco's are color-coded for fast identifi-

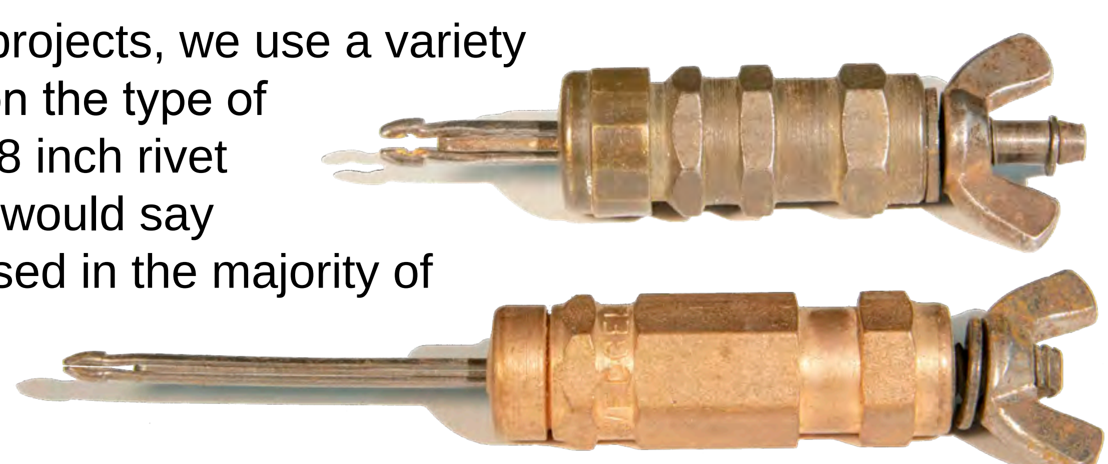

Figure: 3 Draw Type Cleco

cation. (Figure: 4) During a typical repair or construction project, you may end up with several different rivet and cleco sizes, all within the same subassembly. As the cleco's come in and out of the structure it's very common that they get mixed up. But having them color-coded makes it very convenient. And easy to sort out at the end of a project. It is normal during a construction process to drill all of the holes to the actual fractional rivet size. For example using a 3/32 drill bit to drill for a 3/32 rivet. This allows us to assemble the structure and have slight movement as we proceed with clecoing the structure together. It's not uncommon that during the assembly process there is some movement within the structure creating a slight offset in the rivet holes. As a result, using the fractional size drill bit initially allows us to return later to "ream" the holes to their final dimension after the structure is solidly in place with cleco's. This results in rivet holes with much better alignment, which is the cornerstone to a well-built aluminum structure. The corresponding final drill bit size can be found on the body of the cleco's in the graphic depicting color coding. These final drill bit sizes are only a few thousandths of an inch larger than the fractional rivet size. And you will need the corresponding numbered drill bit if you want to avoid frustration. It's nearly impossible to fit an aluminum rivet into the fractional drill bit hole size. They hang up and get stuck, both trying to install, and trying to remove if they won't insert all the way. The cleco's are designed to work with both the fractional drill bit as well as the number drill bit. If you find that the cleco does not grab the sheet-metal during installation, this is a sign that the rivet hole has been "hogged" out. If the cleco pops out of the hole, it is generally an indication that an oversized rivet may be necessary.

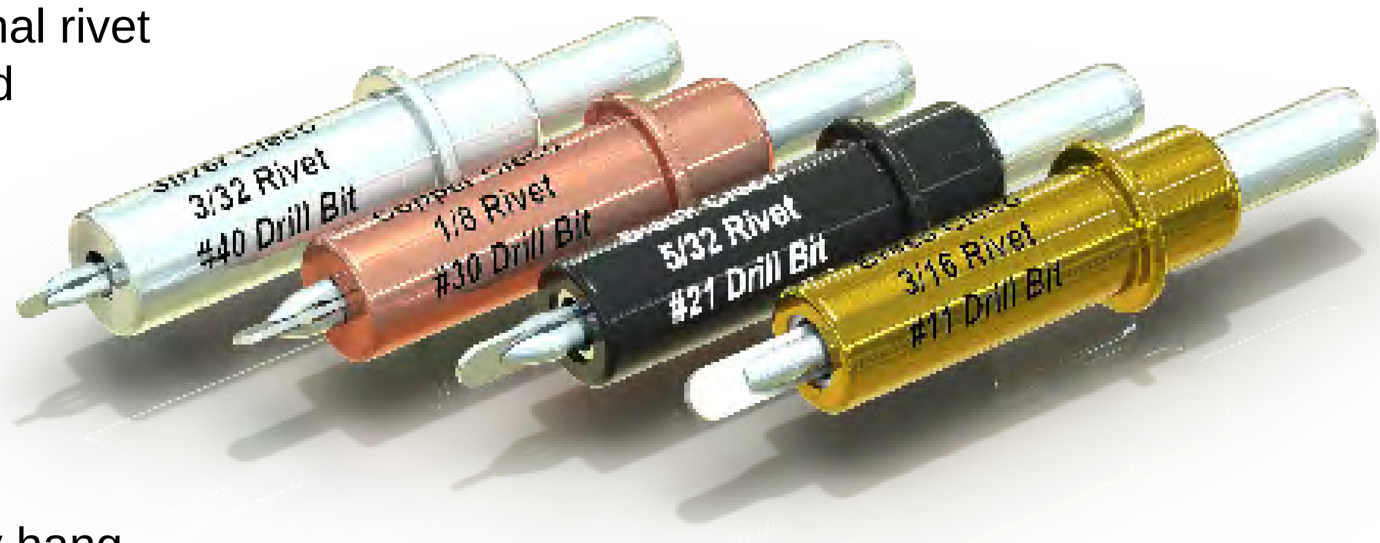

Figure: 4 Color Coded Cleco's

As you can see, there's a cleco for just about every sheet-metal project you could think of. And even if you're not working on a sheet-metal project today, one of the more useful cleco's used on a day-to-day basis for all kinds of projects, is the cleco clamp. (Figure: 5). It's kind of like a spring-loaded "C" clamp. It's small enough that it can be used in some fairly tight quarters and strong enough that we find it useful for a myriad of different holding tasks. When we use it for sheet-metal, its primary use is for holding the pieces of material together while you're making the first couple of holes to install a regular cleco. And unlike regular cleco's where you will probably need several hundred to build


Figure: 5 Cleco Clamp

a sheet-metal airplane, having only a handful of these around will usually find their way into many day-to-day projects.

Figure: 6 Cleco Pliers

Last but not least, cleco pliers. Over the years the cleco plier design has settled into a "one design fits all" style. But looking in our toolbox we found quite a selection of different styles of cleco pliers.(Figure: 6) Surprisingly, we find that the angle available from each of the different style of pliers provides the ability to install and remove cleco's in other than traditional external applications. When doing complex repairs we are often reaching for a different pair to reach into areas where the traditional pliers just don't seem to fit. These different designs are a collection from a lifetime of doing sheet-metal work. Keep your eyes peeled, every once in a while you'll see one of the weird pair show up on eBay.

Although we consider sheet-metal construction an "art", it is an art worthy of mastering. And to this day, it is still the most popular construction method when it comes to the experimental aircraft builder. And for the sheer enjoyment of building, aluminum sheet-metal is by far our favorite construction medium.

Spark Plugs and The Rotax Engine: Part 1

RAINBOW Aviation Services™

We continue to see problems surrounding the use of spark plugs in Rotax engines. Many of the rules which we have used in the past for typical aviation type spark plugs, used on air cooled engines, no longer apply to the automotive type spark plugs used in a Rotax engine. As with most technical subjects, an underlying understanding of the theory and physics involved is essential to our ability to make good judgments about the use and operation of spark plugs. So let's start with the basics.

The spark plugs used in the Rotax engines are specific to each type of engine. Figure: 1. The most prolific of the Rotax engines is the 912S 100 hp and it uses the DCPR8E. Figure: 2. Using this plug let's look at the part number designation and what each one of the numbers and letters indicate for the design of the spark plug.

Spark Plug Size: The (DC) in the part number is the thread diameter and pitch. Looking at the NGK part numbering chart, it indicates that this is a 12 mm diameter spark plug with a 1.25 mm pitch on the threads and uses a 16mm wrench on the hex portion of the spark plug.

Reach: The Last Letter in the part number (E) indicates that this plug has a 19 mm thread reach. This is measured from the base of the plug, above the gasket, to the last thread.

Rotax Spark Plug Application Chart				
Rotax 2 Stroke Engines	Rotax 912 80 HP	Rotax 912S 100 HP	Rotax 912IS Fuel Injected	Rotax 914 Turbo
NGK	NGK	NGK	NGK	DENSO
BR8ES	DCPR7E	DCPR8E	DCPR8E	X27EPR-U9

Figure: 1 Rotax Spark Plug Application Chart

Shape: The (P) in the part number indicates this plug has a projected center electrode insulator. The projected center electrode insulator is what you would normally recognize as a typical spark plug and is of course the most common type.

Construction: And the (R) in the part number indicates this is a resistor type spark plug. When a spark jumps the gap on a spark plug, it creates a high frequency burst of energy. This creates radio frequency interference or (RFI) which can generate significant interference with your radios and other electronic equipment. Placing a resistor within the spark plug significantly reduces this RFI. Figure: 3.

Heat Range: The (8) in the part number is an indicator of the heat range. The heat range of the spark plug is designated by the ability of the spark plug to dissipate heat that is absorbed from the combustion chamber. The heat within the insulator nose is transferred into the body of the spark plug and out into the cylinder head which is cooled by air or by water/antifreeze.

A hot spark plug is just as it sounds. It is designed to hold more heat at the insulators nose in order to burn off oil or carbon deposits. A hot spark plug is designed with a longer ceramic nose and a much smaller area of the ceramic insulator in contact with the spark plug body. This slows down the transfer of heat from the ceramic insulator into the cylinder head. This spark plug design is useful on engines that are designed with low compression ratios or engines that typically operate at a lower manifold pressure continuously. Insulator temperatures less than 450°C / 842°F will not burn off carbon deposits. Because carbon is a good conductor of electricity, this accumulation of carbon deposits on the insulator nose will form an electrical path to ground which can cause the spark plug to misfire. This same condition can occur on or aircraft that spends a considerable amount of time at idle or taxiing. One of the purposes for an engine run-up, just before takeoff, is to ensure that we have not fouled a spark plug. We also have the added benefit of burning off any carbon accumulations on the spark plug insulator during the run-up procedure. Figure: 4

A cold spark plug on the other hand is designed to transfer heat more efficiently from the center electrode and ceramic core into the cylinder head. The ceramic insulator on a cold plug has a larger surface area in contact with the spark plug body when compared to a hot plug. On the high-performance engines and engines with higher compression ratios the temperatures and pressures within the combustion chamber are more significant. Looking at the spark plug application chart Figure: 1, you can see that the 80 hp Rotax 912 uses a spark plug with a heat range (7), while the 100 hp Rotax 912S and IS use a spark plug with a heat range (8), and the turbocharged 914 uses a heat range (9). The engine manufacturer typically selects a plug with a heat range corresponding to the design of the engine. The more aggressive the performance, the cooler the spark plug requirement in order to keep the insulator and

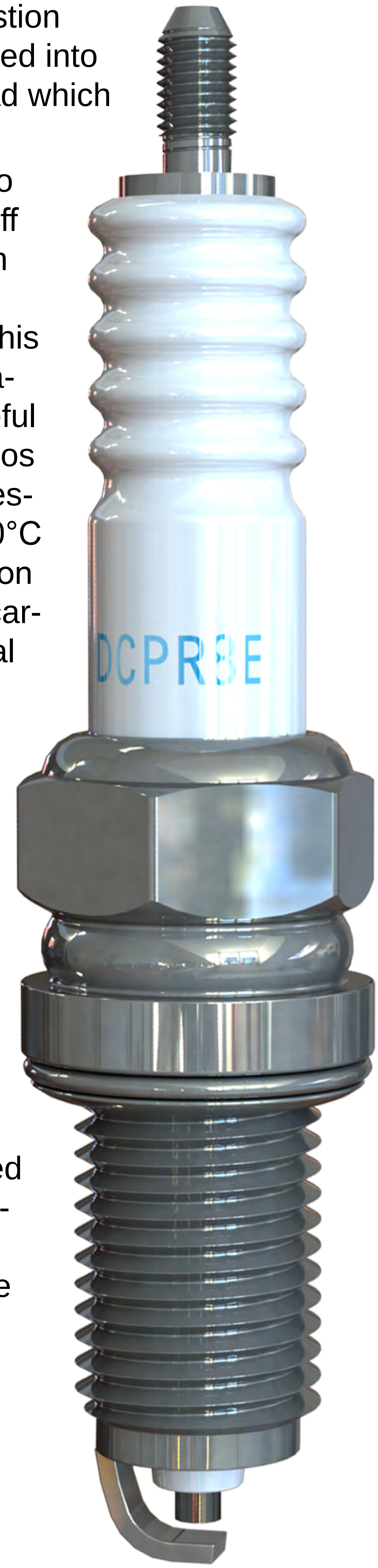

Figure: 2 NGK DCPR8E Spark Plug

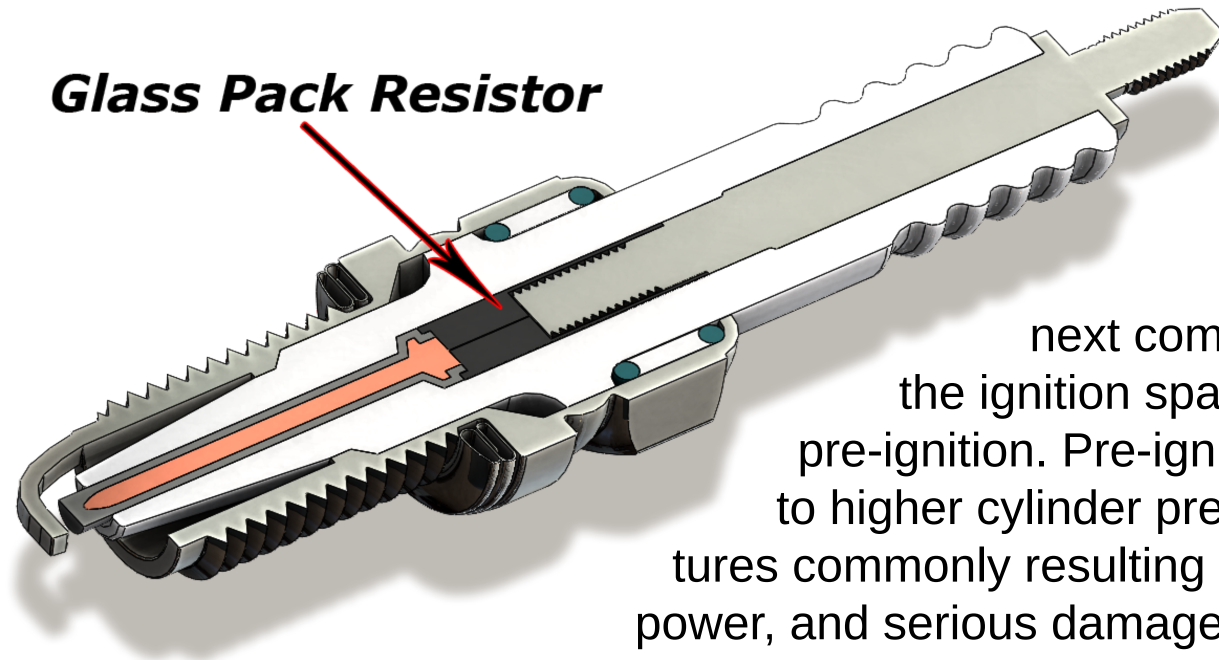

Figure: 4 RFI Suppression Resistor

center electrode from becoming too hot. A spark plug that runs too hot may ignite the fuel on the next compression stroke before the ignition spark. This is known as pre-ignition. Pre-ignition can in turn lead to higher cylinder pressures and temperatures commonly resulting in detonation, a loss of power, and serious damage to the engine. Temperatures in excess of 870°C / 1598°F can lead to pre-ignition. Insulators approaching these temperatures and can be identified by the insulator being blistered or white in color. The NGK spark plug provides a design that is less susceptible to fouling by incorporating a longer ceramic nose which allows the ceramic to maintain a high enough temperature at low power settings while simultaneously

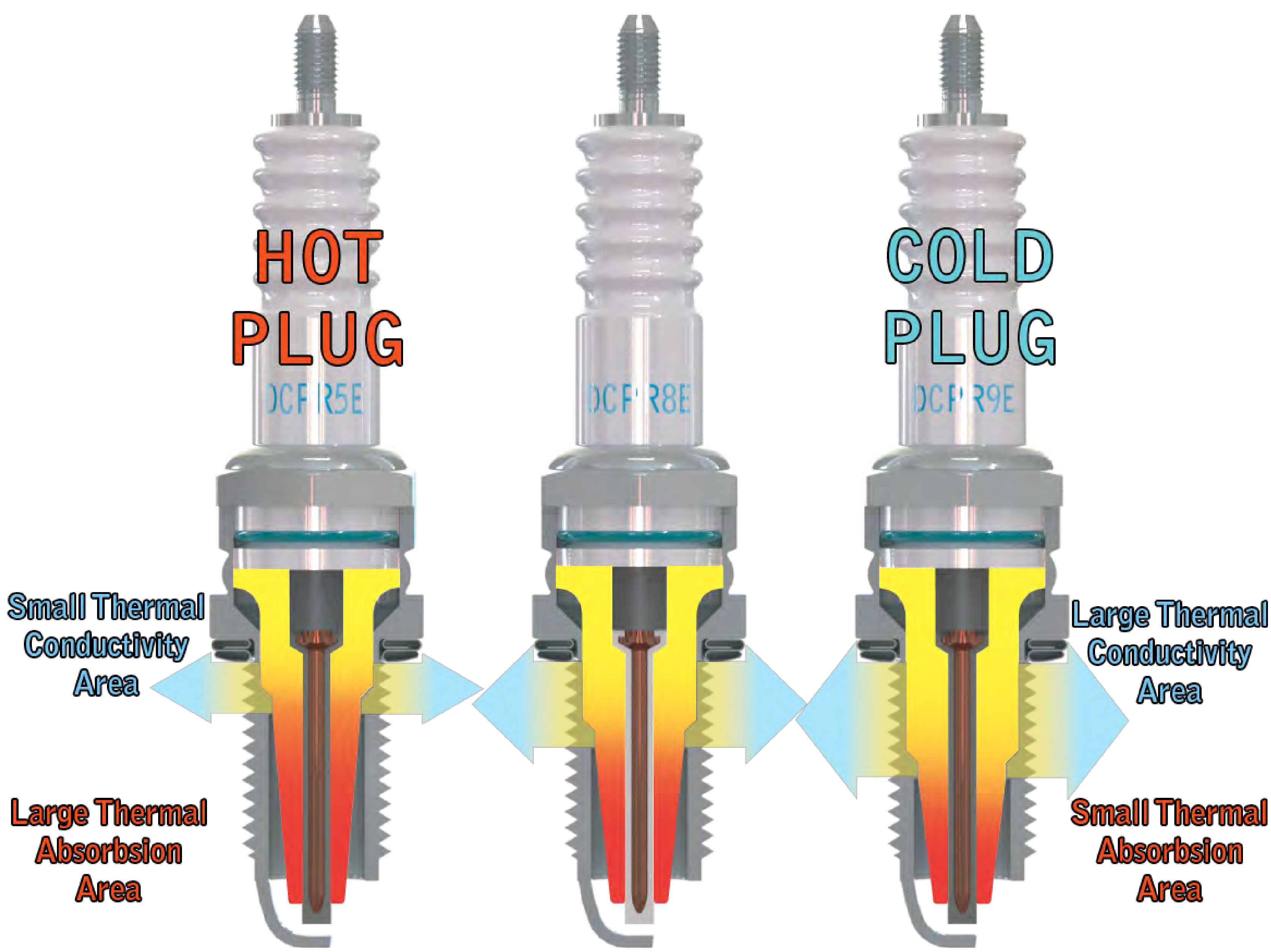

Figure: 3 Spark Plug Heat Range

using a copper core in the center electrode of the spark plug which transfers heat very efficiently out of the spark plug nose raising the pre-ignition rating. This provides for a very broad thermal range particularly suited for Rotax powered aircraft applications.

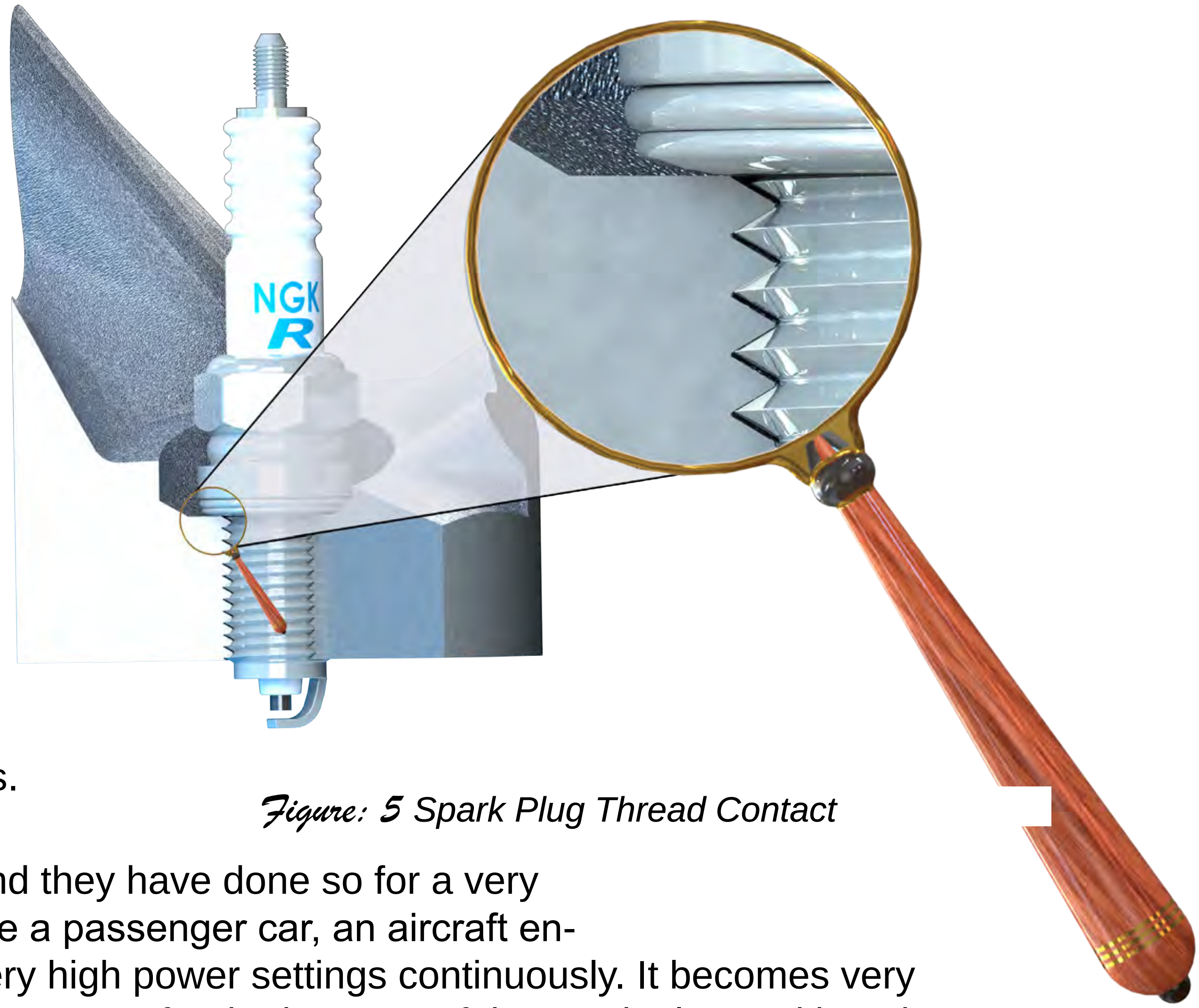

Figure: 5 Spark Plug Thread Contact

Rotax is gone one step further, and they have done so for a very good reason. Unlike a passenger car, an aircraft engine operates at very high power settings continuously. It becomes very important to be able to transfer the heat out of the spark plug and into the cylinder head. In order to significantly improve this heat transfer rate, Rotax adopts the use of a heat transfer paste on the spark plug threads of the 9 series engines. If we look at a cross-section view of the spark plug threads installed into the cylinder head and zoom in on a microscopic level, we can start to see how we could significantly improve the heat transfer rate. Figure: 6. When we begin to torque the spark plug into the cylinder head, the top of the spark plug threads make contact with the bottom of the threads on the cylinder head. This pressure on one surface of the spark plug thread naturally pulls the other side of the spark plug thread away from the opposing surface of the spark plug thread in the cylinder head leaving a small gap on the opposite side of the thread. The air gap between these two contact faces acts as a very efficient insulator and restricting the heat transfer across these two surfaces. By applying a small amount of heat transfer paste to the threads of the spark plug, we can bridge this gap and significantly improve the heat transfer from the spark plug to the cylinder head. The heat transfer paste that is used is very similar to that used in the computer industry for transferring heat from a computer chip into a heat sink. The Rotax part number for this heat transfer paste is 897-186 and it is shown in the parts catalog as Wacker P-12. Figure: 5. There are also several after-market brands of heat transfer paste sold by California Power Systems, Lockwood Aviation, and Leading Edge Airfoils. These are the three primary companies offering Rotax parts and supplies for sale in the United States. These companies generally do a good job at setting the viability of after-market products used on the Rotax engine. Be cautioned, however, since there are many other heat transfer paste products that are not equivalent to the P-12 and won't provide the same kind of heat transfer performance required by the Rotax engine. One of the most common indicators that the heat transfer paste is inadequate is that during the removal of the spark plug the heat transfer paste appears dry and powdery on the spark plug threads. A high quality heat transfer paste will remain sticky and gooey throughout its service life.

This efficient transfer of heat from the spark plug insulator into the cylinder head is precisely the reason that spark plug torque is so very important. A spark plug that is under torqued does not make good contact with the cylinder head. This allows heat to build up within the center electrode and ceramic core creating the dilemma of pre-ignition just as if we had a spark plug with improper heat range rating installed pleading once again to pre-ignition/detonation and subsequent failure of the engine.

Over torque of the spark plug can damage the threads in the cylinder head. This can in turn reduce the ability of the spark plug to transfer heat into the cylinder head. Both Rotax and NGK recommend against the use of an anti-seize compound on the spark plug threads. There are several reasons for this. First, the anti-seize compound significantly reduces the friction and over torquing the spark plug becomes very likely. Second, the anti-seize compound is typically an electrical conductor, which, if it propagates to the electrodes, can short out the spark plug causing ignition failure. NGK manufacturers its spark plugs with a corrosion resistant coating that is designed to be installed into the cylinder head without any thread lubrication. This is the recommended procedure for the Rotax 2 stroke engines.

Figure: 6 Heat Transfer Paste

In part one of this article, we've talked primarily about the theoretical aspects of the spark plug in the Rotax engine. As you can see, Rotax is put a lot of thought into the selection of the spark plugs which they use in each of their particular engines. Keep in mind that these spark plugs are selected for a multitude of reasons, and they have an extremely good performance and safety record in the Rotax engine. If you find yourself thinking about using a different spark plug, other than that which is recommended by Rotax, you might want to rethink your thought process. If you're using the spark plugs recommended by Rotax and your engine is still not running correctly. It's probably not the spark plugs that are the cause. In part two of this article we will take a look at the more practical aspects of inspection, installation, and maintenance of the spark plugs installed in the Rotax engine.

Carol and Brian Carpenter are owners of Rainbow Aviation Services in Corning, California. For more Information visit www.rainbowaviation.com

Spark plugs and the Rotax Engine
Part 2

RAINBOW Aviation Services™

In part 1 of this article, we discussed the theoretical aspects of the spark plugs installed in the Rotax engines. In this article, we will take a more in-depth look at the practical aspects and the “how to” of the spark plug in the Rotax engine.

Spark Plug Removal. When removing the spark plugs, during an annual inspection or any time for that matter, keep in mind that there is a lot of information to be had by “reading the spark plugs.” A spark plug rack is a useful way to keep track of the cylinder position of the spark plugs as you remove them. The spark plug rack should be labeled with both the cylinder number as well as top or bottom position. (Figure 1) If you don’t have a spark plug rack, you can simply make one from a cardboard box by cutting a couple of holes in an X pattern and labeling them with a magic marker. Place the spark plugs with the electrode end facing up so that you can “read” them. In part 3 of “Spark plugs and the Rotax Engine” we will take an in-depth look at troubleshooting the Rotax engine by “reading” the spark plugs. Keeping track of the spark plug location is not just for identifying potential problems within a particular cylinder, but for more practical reasons as well. We want plugs located within a single cylinder to have nearly identical wear pattern so that the redundant ignition systems will have a similar spark profile. If one spark plug is worn significantly more than the other plug within that cylinder, the ignition system with the worn spark plug will have to work harder than the cylinder with the new spark plug. This will produce an uneven ignition event within the cylinder. If the plugs are to be reinstalled into the engine, they should always be placed back into the same cylinder from which they

Figure 1: Spark Plug Rack

Rotax Spark Plug Application Chart							
Engine	Rotax 447 Engines	Rotax 503 Engines	Rotax 582 Engines	Rotax 912 80 HP	Rotax 912S 100 HP	Rotax 912IS Fuel Injected	Rotax 914 Turbo
Plug MFG.	NGK	NGK	NGK	NGK	NGK	NGK	DENSO
P/N	BR8ES*	BR8ES*	BR8ES*	DCPR7E	DCPR8E	DCPR8E	X27EPR-U9
New Gap	0.5mm 0.02 in.	0.4mm-0.5mm 0.016-0.02 in.	0.5mm 0.02in.	0.6mm-0.7mm 0.023-.027in.	0.6mm-0.7mm 0.023-.027in.	0.6mm-0.7mm 0.023-.027in.	0.6mm-0.7mm 0.023-.027in.
Tightening Torque	27Nm 238in.lb.	27Nm 238in.lb.	27Nm 238in.lb.	20Nm 177 in.lb.	20Nm 177 in.lb.	20Nm 177 in.lb.	20Nm 177 in.lb.
Plug Change Interval	25 HRS**	25 HRS**	25 HRS**	100*** / 200	100*** / 200	100*** / 200	100*** / 200
Thread Application	Dry	Dry	Dry	Heat Paste	Heat Paste	Heat Paste	Heat Paste

* Use of B8ES Is approved on engines not sensitive to RFI from the ignition system (No Radio Aircraft)
** Inspect spark plugs at 12.5 hrs for new engine and then replace at 25hr intervals
*** Inspect every 100 Hrs, Replace every 200 Hrs, Replace every 100 Hrs if using 30% or more leaded fuel
Note! Always consult the current parts and service manuals for the most up to date information

Figure 2: Rotax Spark Plug Application Chart

were removed, and should be kept as a set. Replacement of one spark plug should warrant the replacement of both spark plugs within that cylinder.

"Drop it once, drop it twice," the second time should be in the garbage can. Never use a spark plug which has been dropped. The potential for micro cracks occurring within the insulator after being dropped is significant enough that it's not worth the risk. The cracks may not initially be causing a problem, but after several hours of operating time, the heating and cooling cycles may cause the cracks to propagate to the point of causing a plug failure. If you're removing the spark plugs on a Rotax 9 series engines for the purpose of doing a compression check, remember the engine is going to be hot. Always wear gloves. The most common reason for dropping a plug is that it's... well... HOT!

Spark Plug Replacement. For the Rotax 9 series engines, Rotax recommends inspection, gapping, and cleaning at 100 hours and replacement at 200 hours. With the exception that replacement is recommended at 100 hours if you use 100 low lead more than 30% of the time. For the Rotax two-stroke engines, the Rotax spark plug application chart lists the NGK BR8ES Spark Plug. (Figure 2) Rotax also recommends the NGK B8ES spark plug that does not contain the internal RFI suppression resistor. If your aircraft contains any kind of avionics or a radio system, you would probably not want to use the non-resistor type of spark plug. However, it is important to recognize that the resistor type spark plugs do reduce the voltage to the spark plug electrodes and typically, you will find that you will have an improved spark with the use of a non-resistor plug. We have seen anecdotal evidence of improved starting performance on two-stroke engines in very cold weather, and with engines mounted inverted when using non-resistor type spark plugs. The two-stroke engines require replacement of plug every 25 hours.

Spark Plug Cleaning. You may be familiar with the spark plug cleaning routine normally associated with spark plugs used in Continental and Lycoming type engines. It is not uncommon that we can use a set of spark plugs, in these type of engines, for 1000 hours of operating time. It's also not uncommon that we will need to clean these spark plugs on a fairly regular basis. Every 50 to 100 hours of operating time would be a normal interval to be inspecting and cleaning spark plugs on a typical general aviation, training aircraft. The spark plugs used in these type of aircraft can cost anywhere from

Figure 3: Wire Style Gapping Tool

$30 up to well over $100 each. With these costs, spark plug cleaning becomes a necessary routine. However, when we're talking about the automotive type spark plugs, which we use in a Rotax engine, it is not considered normal practice to clean these type of spark plugs especially with an abrasive blaster. The cost of the NGK spark plugs are in the neighborhood of $2.50 to $3.50 each. Even the cost of labor to properly clean and test these spark plugs makes it an impractical exercise. There is some anecdotal evidence, which suggests that the use of abrasive blasting media to clean these type spark plugs increases the surface roughness on the ceramic and lessens the spark plugs ability to burn off the carbon build up on the insulator. The Rotax manual is very clear on the subject, "Attention: Never clean spark plugs with an abrasive cleaner." We do know that the use of media blasting does help to round off the edges on the electrodes. It is the sharp edges of the electrode that promote a good clean spark. Cleaning, if at all, should be relegated to the task of spraying with carb cleaner and then blowing them out with an air nozzle. If you have a spark plug condition in need of more than this, you would probably benefit from new spark plugs. All of the debate about cleaning automotive type spark plugs in the Rotax engine is really kind of irrelevant. A properly set up, maintained, and operated Rotax engine should never see any problem with spark plug performance in-between the required spark plug inspection or change interval. It is only with engines that have some significant deficiency that require extraordinary spark plug, maintenance.

Gapping the Spark Plug. It is important to note that the part number on the spark plugs are used for a multitude of different engine applications. As a result, the plugs will, typically, not be correctly gapped for your particular application. It is absolutely essential that you check, and if necessary, adjust the spark plug gap. When adjusting the gap on a spark plug, NGK recommends that the maximum adjustment be no more than .008” from the out-of-the-box setting. Adjusting more than .008” will stress the ground electrode or cause a misalignment between the electrodes. Either of these conditions could contribute to poor spark performance. The recommended procedure for checking the spark plug gap is to use a wire type feeler gauge. (Figure 3) This type of feeler gauge is a bit more accurate when the center and ground electrodes are not parallel. Adjusting the spark plug gap is accomplished by moving, (bending), the ground electrode using a plug gapping tool. Spark plug gapping tools can be obtained at most automotive parts stores. The recommended gapping tool is similar to the one shown in (Figure 4). The slots built into the gapping tool should be placed over the ground electrode and very carefully prying up or down to reposition the ground electrode. Make certain that you do not make contact with the center electrode or ceramic insulator. Prying against the center electrode could result in cracking of the insulator. In cold weather, the Rotax manual indicates that gapping to the minimum dimension can assist in engine starting. You might think that you would want to do this on all of your spark plugs, all of the time, but keep in mind the smaller the gap, the easier it is for the spark plug to become fouled and stopped functioning. Vice versa, by gapping the spark plug larger, to avoid spark plug fouling, you can, in turn, make it difficult for the engine to start as well as increase the potential for misfire during normal operations.

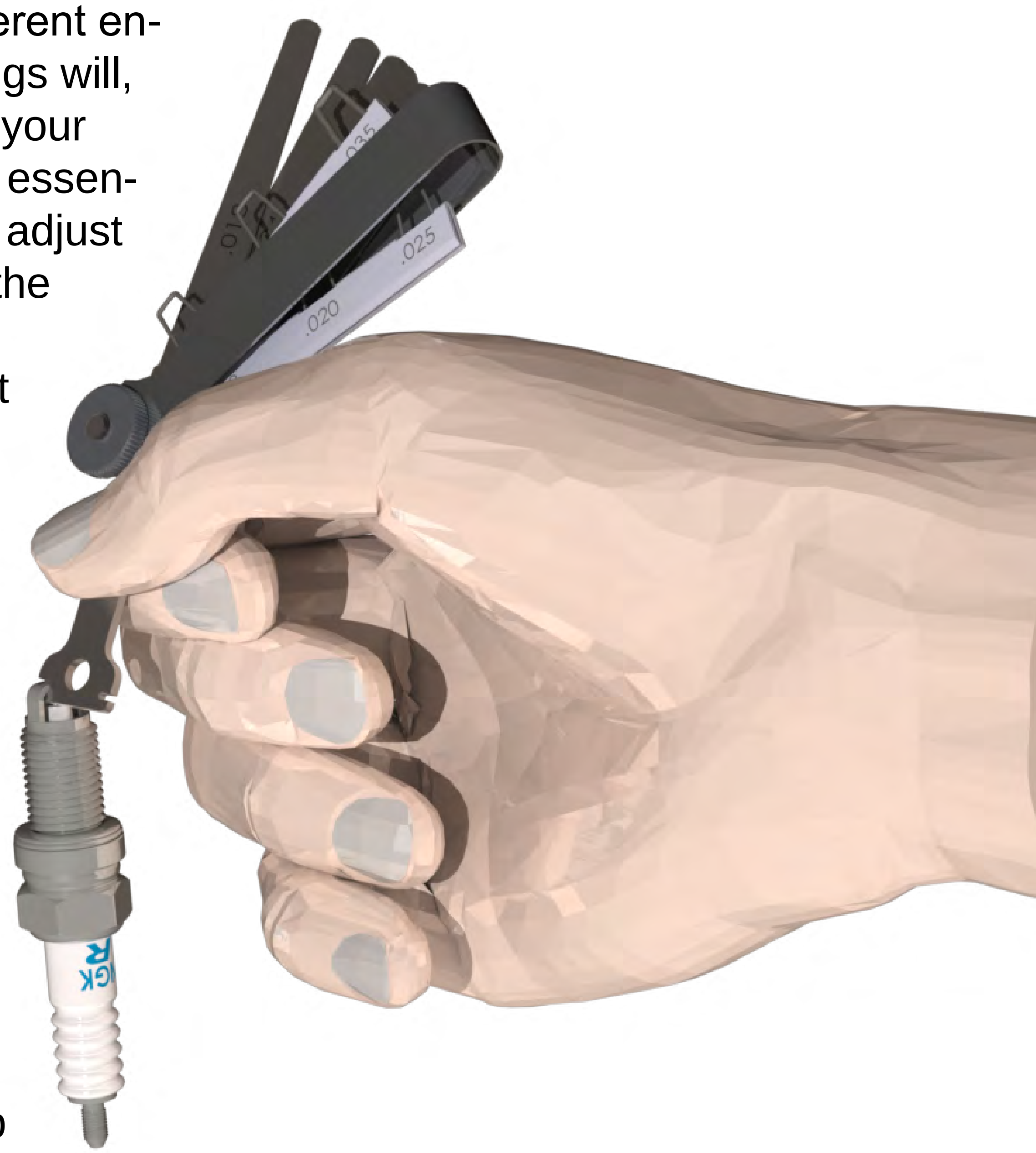

Figure 4: Spark Plug Gapping Tool

Heat Transfer Paste. All of the Rotax 9 series engines call for the use of heat transfer paste on the threads. Last month, in part 1 of this article, we talked about the reason behind the use of heat transfer paste. This is a case where “a little dab’ll do ya.” We would like to ensure that we have heat transfer paste 360° around the perimeter of the threads. Then, using your finger, try to remove as much of the heat transfer paste as possible. This will leave just the right amount paste within the threads of the spark plug body. (Figure 5) We also like to make sure that we keep the heat transfer paste away from the firing end of the spark plug as it can foul the spark plug if it gets on to the electrodes. Normally, we do not apply any heat transfer paste to the last three threads of the end of the spark plug.

Figure 5: *Heat Transfer Paste*

Spark Plug Gasket. We will always be using the gasket that comes with the spark plug when installing the plug on a Rotax engine. Even if were using a CHT probes for example on a Rotax 503, the spark plug and gasket will be installed through the CHT probe heat sink which will be resting directly against the cylinder head. Remember, we are measuring cylinder head temperature not spark plug temperature. This is different than we would typically see on a Continental/ Lycoming type installation where the spark plug gasket is removed and a 1/8" thick copper heat sink thermocouple probe would be installed in its place. When installing a new spark plug, during the torquing process, the gasket will squish considerably before the plug comes up to the proper torque. If the plug is removed and reinstalled, it will only take approximately 1/12th of a turn after it is seated to once again come up to the proper torque. Keep in mind, if you're troubleshooting a problem on the engine, constant removal and installation of the same spark plug can result in the sealing gasket on the base of the plug to be flattened to the point that it no longer is providing an effective seal.

Spark Plug Installation. The Rotax maintenance manuals are very clear about installing the spark plugs on a "COLD" engine only. Check the condition of the threads before installation of the spark plug. Ensure the spark plug has been gapped according to the Rotax specifications. Install heat transfer paste on Rotax 9 series engines. Then, when installing the spark plug, screw it in by hand until it is seated against the cylinder head. Next, torque to the proper torque specifications listed in the Rotax manual for your engine. Use a properly calibrated torque wrench. And ensure that the spark plug socket is properly aligned with the spark plug so as not to damage the insulator.

Solid Terminal versus Threaded Terminal. This is one of those areas where, it seems, everyone has to learn the hard way. When purchasing a set of spark plugs for your aircraft, you can have the right part number and still end up with the wrong spark plug. There are solid terminal type and there are threaded terminal type. The part number is the same, but it is the stock number that is different. Ensure, when you order, that you are in fact ordering type that you need. The Rotax 9 series engines use the threaded terminal type which comes with a screw on top that can be used with other engines with different types of spark plug caps. This screw on cap should be removed for the Rotax 912 engines. (Figure 6) If you accidentally ordered the solid terminal type for the Rotax 9 series engine, they are unusable and will not fit the 9 series caps. With the 2 stroke engines, either the screw on cap, or the solid terminal type will work. However, there are many disadvantages to the screw on aluminum cap. Suffice it to say, it is standard practice to order the solid terminal type for all of the two-stroke engines. There been many an engine failure as a result of the screw on cap failing.

Figure 6: Threaded Terminal Spark Plug

We have provided a broad overview of some of the differences in the application and procedures when it comes to spark plugs in the Rotax engine. The underlying theme with the Rotax engine is always the same. The information contained within the Rotax manuals remains your ultimate source for successful use and operation. Rotax has put a lot of effort into giving you guidance and reference material for successful operation of your engine. If you find yourself straying away from the procedures recommended by Rotax, you are probably on the wrong track. And the information from Rotax regarding the use of spark plugs is certainly no exception. The good news is, the spark plugs used in the Rotax engines are very seldom the cause of any problem, moreover, they, most often, bare the telltale signs and symptoms of other problems brewing inside your engine. In part 3 of this article, we will look at these telltale signs and discuss how to "read" the spark plugs.

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Spark plugs and the Rotax Engine
Part 3

RAINBOW Aviation Services™

In part 1, we discussed the theoretical aspects of the spark plugs. In part 2, we talked about the more practical aspects of installation and maintenance of the spark plugs installed in the Rotax engine. In this, part 3, we are going to take a look at using the spark plug as a troubleshooting tool.

The engine will continuously communicate her condition to you through a multitude of sources. One of the most powerful sources of information about an engine's internal condition comes from what the spark plugs have to tell you. We call this "reading" the spark plug. (Figure: 1)

Figure: 1 Reading a Spark Plug

One advantage of reading the spark plugs is that they don't often lie. Engine instrumentation can give us a lot of clues about what's going on inside the combustion chamber, but they are limited, both in the scope and in their accuracy. We see aircraft owners pulling their hair out, modifying the engine, trying to make it operate in a configuration so that the instruments read "normal", only to find out months later that their instrumentation has been indicating incorrectly all along. By this time, they have modified the engine so far from the stock configuration that the road back to proper operation if often frustrating and expensive.

When we talk about reading the spark plug, we are primarily talking about reading the color of the ceramic insulator that surrounds the center electrode. The automotive industry, and in particular the racing industry, has carried this reading of the spark plugs to a very fine, nuanced science. And although engine to engine readings vary substantially, we can take away from some general principles that you should be able to apply to your particular engine. It is common that we can get information about all segments of the engine operation from idle to full throttle by looking at selected segments of the spark plug. Idle operation can be revealed by looking at the face of the threaded spark plug body. Midrange, the place where you spend most of your operating time on the engine, shows itself primarily towards the end of the ceramic insulator where the center electrode protrudes. And full throttle operation is more indicative of a ceramic insulator deep inside the area where the ceramic makes contact with the spark plug body. Now I caution you, these principles need

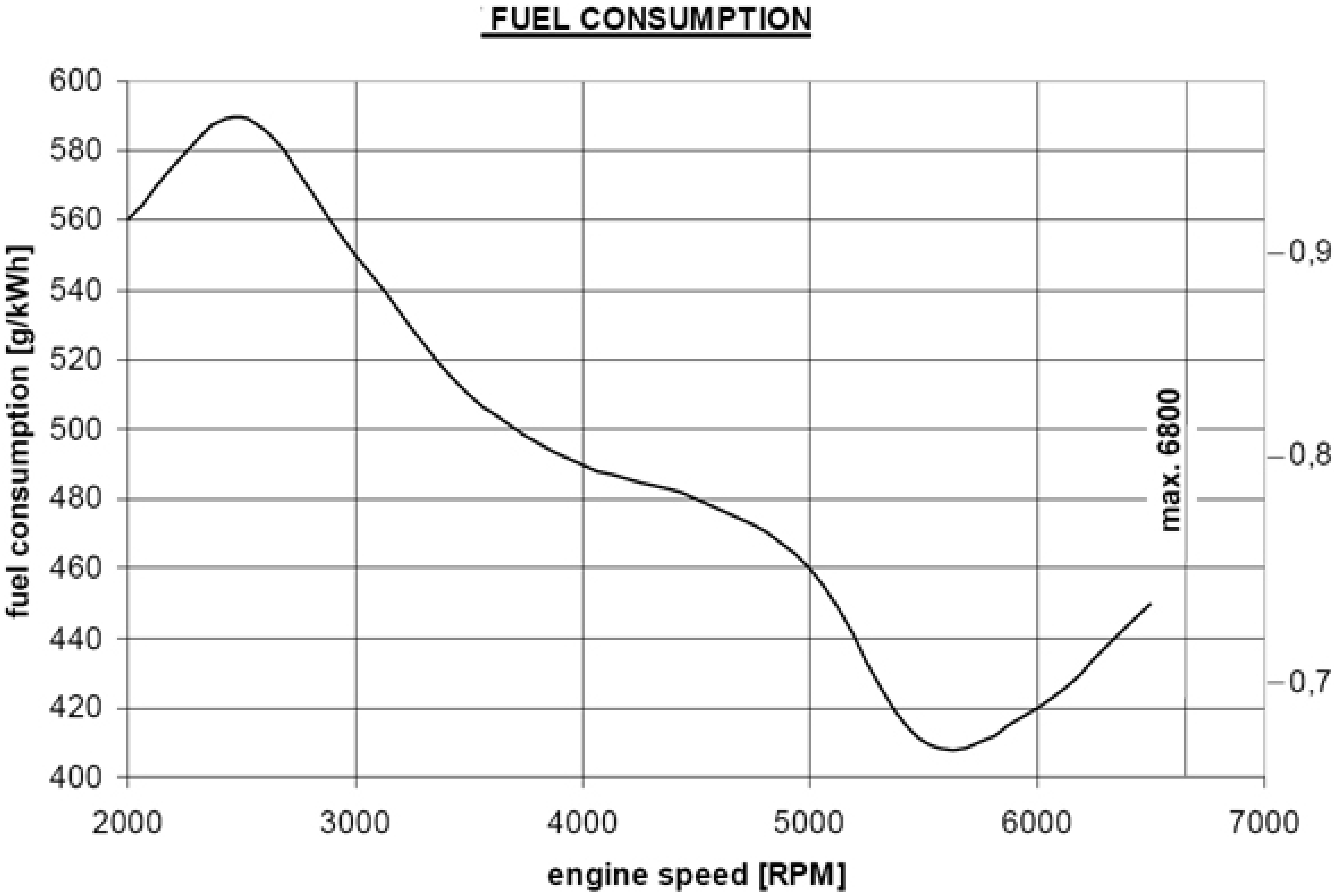

Figure: 2 Rotax 582 Fuel Consumption Chart

to be associated with a significant understanding of the operating characteristics of your particular engine. Even the visual appearance of a Rotax 582 two-stroke engine versus a Rotax 912 four-stroke engine under normal operating conditions will have a substantially different appearance.

We can work with the generic principles that a hot/lean running engine will burn off the carbon deposits and leave a white ceramic insulator. And a cold/rich running engine will not completely burn the fuel deposits and leave dark black deposits on the ceramic insulator. A range of colors from white moving through the browns and onto black can give us a significant range of color that correlate with combustion chamber temperatures. Working with the Rotax 582 fuel consumption graph, (Figure: 2) we can correlate the engine temperatures with the engine (EGT) exhaust gas temperatures. The Bing carburetor is designed to provide a relatively rich mixture at idle. This rich mixture is necessary and normal at idle (2000 RPM). This is because the Bing carburetor does not incorporate an accelerator pump. The accelerator pump on a conventional carburetor is used to provide additional fuel during the throttle advance and acceleration process. The Bing carburetor eliminates this additional mechanical component and instead relies on the excessively rich mixture at the idle settings to provide the additional fuel for acceleration. As a result, we would expect to see a rich mixture on the area of the spark plug that garners idle information. The Rotax 582, like many other engines, is designed to operate continuously around 75% power. If we look at the fuel consumption chart, we can see that this is the design point at which the engine is intended to get the most efficient fuel consumption. This will also be the leanest mixture and hottest EGT settings. And when we look at the ceramic insulator, near the center electrode, we will see the result of this leaner mixture. When operating correctly the insulator will garner a nice tan or light brown color. This process is so accurate that often times you will see variations in color around the perimeter of the ceramic insulator. This is normal and generally a result of the flame front travel emanating from each spark plug burning the fuel in a slightly different pattern as it crosses the combustion chamber. Now, if we follow the fuel consumption curve even further beyond the 5500 RPM cruise position, towards full throttle, we can see that the mixture now starts to increase and you will notice that the mixture gets significantly richer as we reach the full throttle position. This is designed into the engine/carburetor to utilize excess fuel at these higher power settings to act as a combustion chamber cooling agent. As a result, we should see the spark plug insulator turn to a darker brown color in the area that would indicate full throttle operation. Keep in mind that the more time spent at any one of these power settings, the more influence that those conditions will have on the other areas that we are trying to read. An hour's worth of flight in the traffic pattern, doing touch and goes, generally will render a fairly good representation of idle, midrange, and full throttle operation, all on the same spark plug. Reading a spark plug after only a few minutes of operating time at any setting can be quite misleading.

Figure: 3 Carbon Fouling

Now that we have covered the basics of reading a spark plug, let's talk a little bit more about some of the most common anomalous indications that we might see.

Carbon Fouling: (Figure 3) Carbon fouling is an indication of excess fuel within the combustion chamber. It will leave a dark, dry, sooty appearance on a portion or all of the spark plug. There are a multitude of potential causes for having an excessively rich mixture. Troubleshooting fuel related problems can be greatly enhanced by understanding which portions of the carburetor control which stages of throttle operation. (Figure 4)

Worn Needle Jets and Jet Needles. Even if you're getting an indication that the EGT is starting to run a little cooler, it may be worth a look at the spark plugs. It's very common for the needle jet and the jet needle to become worn to the point of causing an excessively rich mixture. This particular type of wear will show symptoms primarily

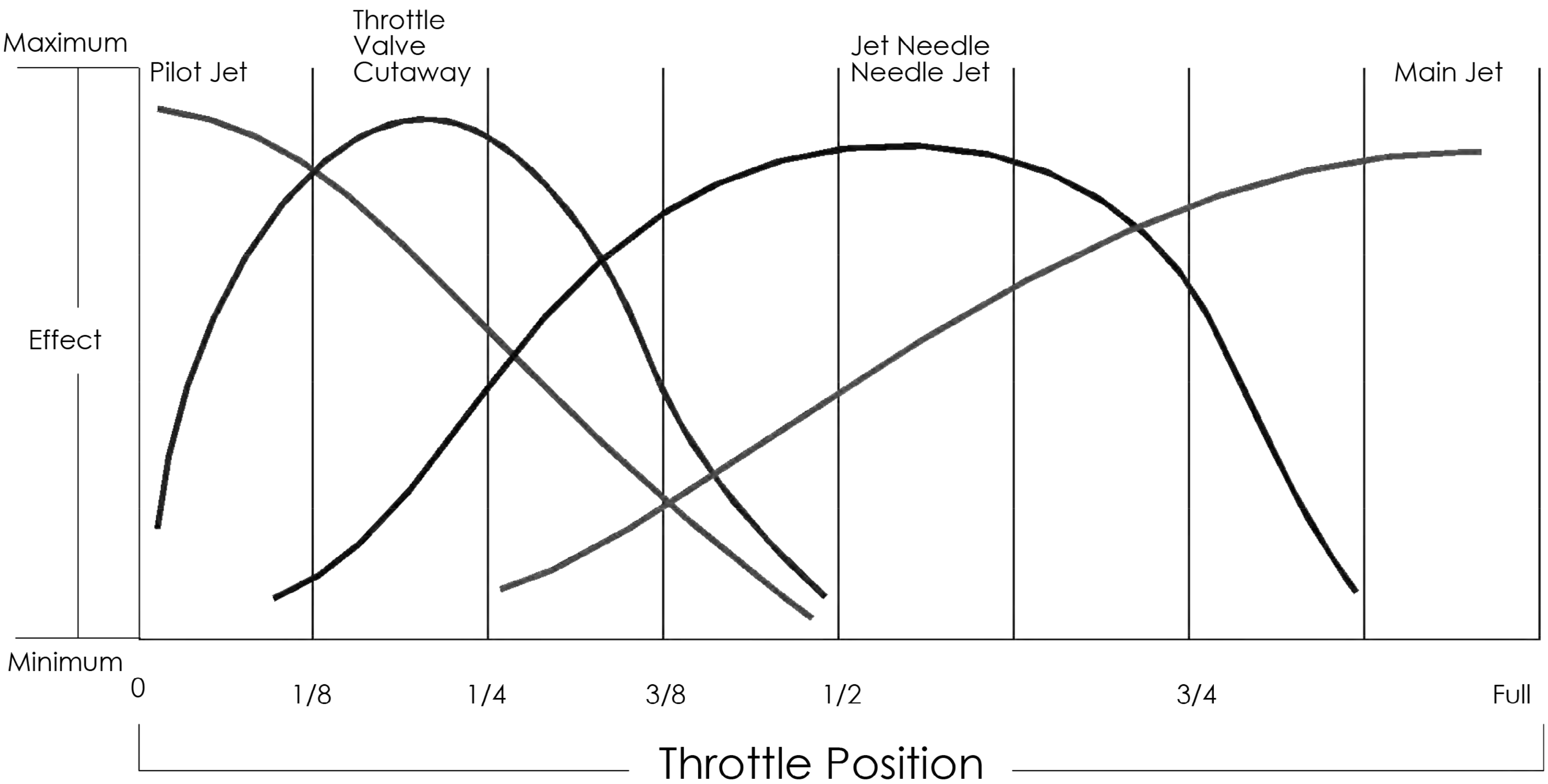

Figure: 4 Bing Carburetor Component Effectiveness Chart

in the midrange. It's not a matter of whether you're going to have this problem or not, but rather, when. Rebuilding the carburetors on the Rotax engine is a normal part of routine maintenance. Even though the Rotax manual specifies a very specific time interval for carburetor rebuild, the wear that dictates the necessity for the rebuild can be exacerbated by improperly synced carburetors, propeller vibration from imbalance or tracking, high moment of inertia propellers, continuous excessively low idle operation, improperly operating engine, or any other condition which causes the engine/ carburetors to vibrate.

Improperly adjusted or sunken floats. Although it is not a new phenomenon to the Bing carburetors, Over the last couple of years we have been dealing with an increased prevalence of sinking floats, particularly on carburetors used on the Rotax 9 series engines. There are several service bulletins from Rotax that address this problem. Even improperly adjusted float arms can render the same symptoms.

Stuck or leaking needle and seat within the float bowl. A contaminated or corroded seat or a malfunctioning needle will raise the fuel level within the float bowl which will in turn enrichen the mixture across the entire spectrum of operation. The Viton rubber tip on the needle is a life limited part and is a common replacement item at carburetor overhaul. A malfunctioning seat as a result of damage or corrosion generally requires the replacement of the carburetor. These problems may also be accompanied by symptoms of fuel continuing to over-fill the float bowl after engine shutdown. Excessive fuel pressure from an auxiliary fuel pump can also cause the condition of off-seating the needle and seat. The Rotax maintenance manual contains a testing procedure for checking the integrity of the needle and seat. In addition, an engine that is not properly synchronized can also cause enough shaking, particularly at idle, to cause the needle seat to off-seat in the float bowl causing similar symptoms.

A stuck choke (enriching valve): Having a sticking choke cable is a very common occurrence. The return spring on the choke is a very lightweight spring and oftentimes does not have enough pressure to return the choke to its off position after release of the choke control. Additionally, if the enriching valve plate has contamination between the seating plate and the carburetor body, this will allow fuel to bypass the normal routing within the choke mechanism, acting as though the choke was in the on position even though the visual position of the choke cable is observed to be off.

Contaminated air filters: Failing to properly service the air filters can cause an excessively rich mixture.

Oil Fouling: (Figure 5) Oil fouling color is similar to fuel fouling however the difference is, with oil fouling the plugs are typically wet with oil whereas with fuel fouling the plugs are typically dry. As you might imagine oil fouling usually means we've got some serious work ahead of us.

Rings: Piston rings that are stuck, broken, or worn could be the culprit. This potential problem can usually be validated through a compression check.

Worn and leaking valve guides. An intake valve guide that is leaking is a different indication than that of an exhaust valve guide leak. Because the intake valve guide leaks into the intake manifold, all of that oil is routed through the combustion chamber and then out the exhaust. The intake valve guide may be suspect if the spark plugs are black, wet, and oily. This oil may be partially consumed in the combustion process and produce black soot in the exhaust and onto the exterior of the aircraft. On the other hand, an exhaust valve guide leaks directly through the guide into the exhaust manifold, bypassing the combustion chamber entirely. In this situation, you may see wet oil on the belly of the aircraft and in the exhaust pipe, but with much less soot by-product. The spark plugs on the other hand may appear perfectly normal. This is where the preflight procedure of running your finger into the exhaust pipe and visually checking the combustion byproducts can be extraordinarily valuable.

Figure: 5 Oil Fouled Spark Plug

Lead Fouled Spark Plug: Lead fouling is characterized by hard, dark, gray, cinder-like globules. Observing some of the characteristics associated with the use of fuel containing tetra-ethyl-lead would be common on an aircraft utilizing mostly 100LL (avgas). This is the primary reason for the spark plug change interval on the Rotax 912 to change from 200 hours operating time to 100 hours. The Rotax 912 does a fairly efficient job of scavenging the tetra-ethyl-lead under normal operating conditions. And even using 100LL exclusively would not normally require maintenance intervention in between the 100 hour plug change interval. Observing an extraordinary amount of lead build up is normally associated with poor fuel vaporization associated with carburetors needing overhaul or repair.

Hot Spark Plug: (Figure: 6) A white clean spark plug free from any color is your most prevalent indication that the cylinder is running hot. Although the Rotax 9 series engines operate normally in an aggressively efficient manner and may appear lighter in color than what you would expect to see on the Rotax two-stroke engine, there will always be some color displayed on the ceramic insulator. In extreme circumstances when a spark plug overheats, deposits that have accumulated on the insulator tip may melt and give the spark plug a white glazed or glossy appearance. This is often accompanied with speckles of what appears like melted glass and it is common to observe melting of the center and ground electrodes. These symptoms are normally associated with conditions of lean mixture or advanced ignition timing.

Figure: 6 Lean Plug

Once again, it's very important that you use this as an educational opportunity to understand some of the principles associated with reading your spark plugs. Understanding that every engine has slightly different operating characteristics and not all plugs will look the same under normal operating conditions. Once you become familiar the process of reading the spark plugs, you will realize what an invaluable resource this is in determining the condition of your engine. I'm amazed that we can have as many in-flight engine related problems as we have in aviation. These engines continuously shout and waved their arms letting us know that there are problems. When you're reading a spark plug it's telling you a tremendous amount of information about the condition of your engine. The engine will help you fix her, if you're simply willing to listen. But as your wife keeps telling you. "you never listen."

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As with most building trades, (electricians, masons, carpenters,) there are time proven materials and a base line method of performing tasks which become “standard practice”. As an aircraft builder, you soon learn that there is also a time proven set of practices and building materials that are commonplace within the aviation community.

If there is one universal commonality among the countless aircraft types, it is the use of steel within the structure in some form or another. From the very earliest of aircraft to even the most current, exotic composite aircraft, there is still steel in some form or another used within the aircraft.

The FAA Aircraft Maintenance Technicians Handbook (FAA-8083-30), Chapter 05, has a great explanation of all of the different types of steels, their chemical composition, their characteristics, and usage.

The Society of Automotive Engineers (SAE) and the American Iron and Steel Institute (AISI), use a numerical index to identify the chemical compositions of the structural steels. Generally, in this system, a four-numeral series is used to designate the plain carbon and alloy steels. The first two digits indicate the type of steel, the second

Figure: 1 Spark Testing Ferrous Metals with a Bench Grinder digit also generally gives the approximate amount of the major alloying element, and the last two digits are intended to indicate the approximate carbon range.

Example: 1010 to 1030 Steels contain carbon in percentages ranging from 0.10 to 0.30 percent is classified as low carbon steel. And another example: 4130 alloy steel also known as Chrome-Molly contains Chromium .8 to 1.1% and Molybdenum .15 to .25% as strengthening agents. It has low carbon content .28 to .33%

Aircraft manufacturers use a wide variety of different steel alloys depending on the necessity in each particular application. Understanding the differences, between all of these types of steel alloys is very important from an aircraft maintenance technician standpoint. However, if we look at experimental aircraft, we see that the overwhelming majority utilize the 4130 chromium molybdenum alloy steel. As a result we see that the majority of suppliers for experimental aircraft only stock the 10XX series, low carbon steels and 4130 Chrome-Molly steel. 10XX series steel is used for low strength requirements at a much lower cost, And the standard for high-strength applications has become the 4130 Chrome-Molly steel. This has greatly simplified the construction applications and reduced the cost for experimental aircraft by allowing suppliers to buy material in greater quantities.

> *"Heat-treated SAE 4130 tube is approximately four times as strong as an SAE 1025 tube of the same weight and size" **

"Molybdenum is a strong alloying element. It raises the ultimate strength of steel without affecting ductility or workability. Molybdenum steels are tough and wear resistant, and they harden throughout when heat treated. They are especially adaptable for welding and, for this reason, are used principally for welded structural parts and

Figure: 2 *1025 Low Carbon (Mild Steel)* assemblies. This type steel has practically replaced carbon steel in the fabrication of fuselage tubing, engine mounts, landing gears, and other structural parts. For example, a heat-treated SAE X4130 tube is approximately four times as strong as an SAE 1025 tube of the same weight and size."*

What this boils down to is this: the average experimental aircraft builder normally only has a couple of types of steel which they may be working with, mild steel and the 4130 chrome-molly steel. The dilemma arises when this aircraft builder is looking at piece of steel. Is it mild steel or 4130? At first glance they may look Identical. You can only imagine the potential hazards with inadvertently welding up a structural component utilizing a piece of mild steel in place of a piece of 4130.

There is a standard shop practice which is used to identify the difference between the different types of metals. We do this by using a standard test called the "Spark Test". A Spark test is a time honored method for identifying different types of ferrous metal. (*Figure: 1)*

There are many on-line resources and videos which talk about this spark test method for metal identification. However, the downside is that most of these tests are designed to identify a large variety of metals found in a junkyard for metal salvage purposes. And, as you might imagine, you're not going to find much 4130 Chrome-Molly steel at your average junkyard. As such, these on-line resources fall short for the average aircraft builder.

So let's talk about your shop and specifically look at the differences between the 10xx series low carbon steel and 4130 steel when it comes to the spark test.

The spark test is conducted using a standard bench grinder. While applying the metal to the grinding wheel, we can observe the resulting sparks and their characteristics. Each type of metal will produce different results. With experience and knowl-

Figure: 3 *4130 Chome-Molly Steel*

edge, you will soon become confident in your ability to identify one type of metal from another. When we observe the spark, we will be looking at the length of spark, the color of the spark, and the shape and placement of the Forks, Sprigs, and Starbursts produced by the spark.

1025 Low Carbon Steel: easily identified by the long straight shafts that emanate from the grinding wheel with a minimum of “Forks”, “Sprigs” or “Starbursts”. The spark can vary more in length, and the color of the sparks will be mostly white, and the forks will be more prevalent than sprigs or starbursts. (*Figure: 2*)

4130 Crome-Molly Steel: easily identified by the abundance of “Starbursts”. The “Starburst” is just as it sounds, a mini explosion of burning metal particles. In fact, this is exactly what produces that same effect in fireworks. Burning different metals and compounds causes different colors of light to be formed. The gold color is primarily from the burning iron, which makes up about 98% of the steel. 4130 has slightly more orange color in the sparks than mild steel. The sprigs or starbursts occur along the entire length of the spark pattern. (*Figure: 3*)

If it is simply a matter of differentiating between low carbon steel and 4130, the starbursts or the lack of the starburst is a dead giveaway.(*Figure: 4*)

Of course, you will find slight variations in the identification process primarily from things like the speed and diameter of the grinder, the material or coarseness of the grinding wheel, and even the material alloy or quality from one supplier to another.

Figure: 4 The “Starburst”

We recommend that anytime you purchase new material that you save a small scrap to be used as a baseline test piece. Take a magic marker and label it with the corresponding alloy. Later on, If you're having trouble deciding what metal you are working with, you can simply go back to your selection of test pieces and match-up the material using the spark test method on both pieces.

This is a very reliable, simple process, and with a little bit of practice, you should have no trouble identifying the different ferrous metals within your shop.

References:

* The FAA Aircraft Maintenance Technicians Handbook (FAA-8083-30) chapter 05

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Starter Relay

Whether you call it a starter relay, a starter solenoid, or a starter contactor, we are probably talking about the same thing. The terms have been interchangeably used so often, that they are now all considered expectable to describe the same thing. A relay, by definition, is an electrically operated switch. A "contactor" is also an electrically-controlled switch. Typically Identified by the controlling circuit of a contactor operating at a much lower power level than the switched circuit, in our case, a 12 V - 3 amp electromagnet coil controlling a 12 V 150 amp starter motor. Another example might be a 12 V DC electromagnet coil controlling a 220 V AC industrial motor.

On the other hand, the term solenoid, by definition, refers to the coil (electromagnet) within our starter relay. When energized, it creates a controlled magnetic field which converts electrical energy into linear motion. This is accomplished by creating a magnetic force that displaces the soft iron core of the "contactor" engaging the "switch". The switch in this case, is made up of a large heavy-duty "washer" attached to the center core and two copper studs exiting each side of the relay. (Figure: 1) Solenoids are not just used for controlling electrical switches ,but can be can be used to control a whole host of operations from hydraulic and pneumatic valves to mechanical mechanisms. The term solenoid started to become synonymous with the starter relay when manufacturers replaced the old Bendix (mechanical starter engagement) systems with solenoid controlled starter engagement systems. These solenoids engage the starter drive gear physically into the engine while simultaneously engaging an integral contactor system which

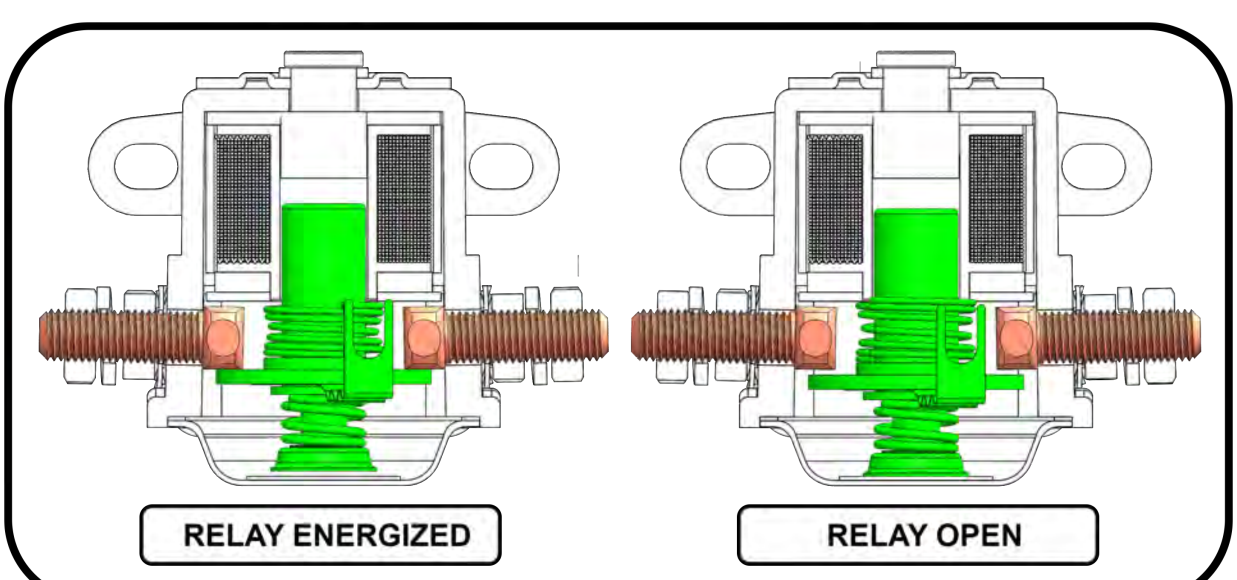

Figure: 1 Operation of the Starter Relay

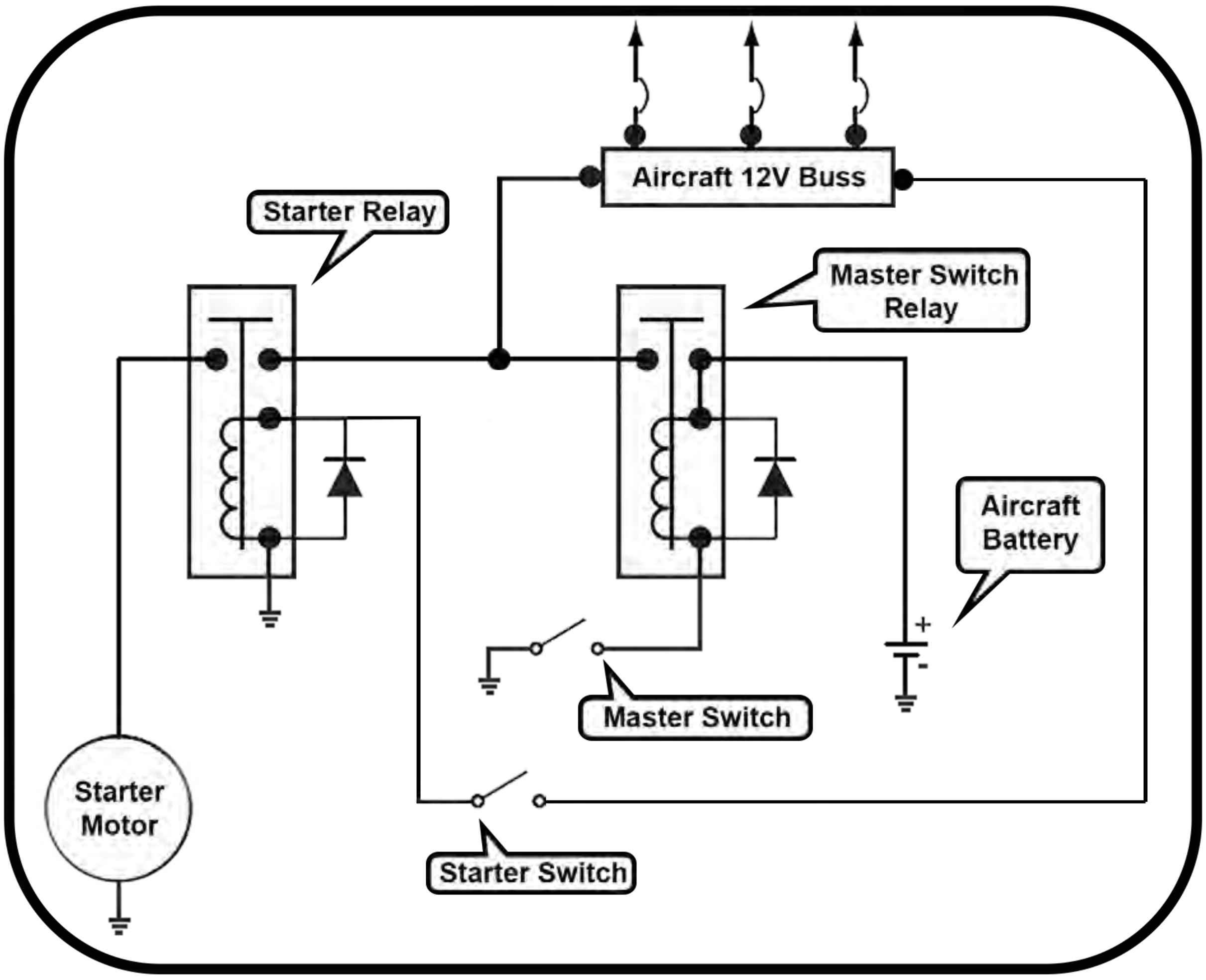

Figure: 2 Simple Starter Circuit

in turn electrically energizes the starter motor.

In (Figure: 2) we have a simple diagram of a starter installation. Although it is important to recognize that there are a multitude of different types of starter systems, this type of installation is typical of experimental and light sport aircraft. In this diagram it is evident that the starter relay and the master switch relay are not at all the same. A master switch relay is engaged by grounding the master switch, whereas a starter relay is engaged by applying 12 V through the starter switch. In our diagram, and 3D model, the starter relay is grounded internally to the mounting bracket. The small post (terminal) labeled "S" (switch) is attached to the starter switch. 12V is applied to the relay coil when the starter switch is engaged. The other small post labeled "I" (ignition) (Figure: 3) is used on automotive installations that use a resistor in the primary circuit to lower the ignition coil voltage. This post has a flexible copper strap attached to the center core washer. When the relay is engaged, a full 12V is temporarily supplied through this post to the coil to help start the engine. On aircraft systems where we use a Bendix drive, i.e. Lycoming, or a starter sprag clutch, i.e. Rotax, this post is not used. Keep in mind that this post will be hot during start and as such we normally keep it protected from shorting. On occasion, we will see builders attach a wire from this post to an indicator light on the dash to indicate when the starter is engaged. For aircraft using this type of internally grounded stater relay it is important to note that proper grounding is critical. If you have a composite aircraft or are mounting your starter relay to a painted firewall, you may need to attach an additional wire from the mounting bracket to a ground buss to insure reliability. On composite aircraft, we typically use a different

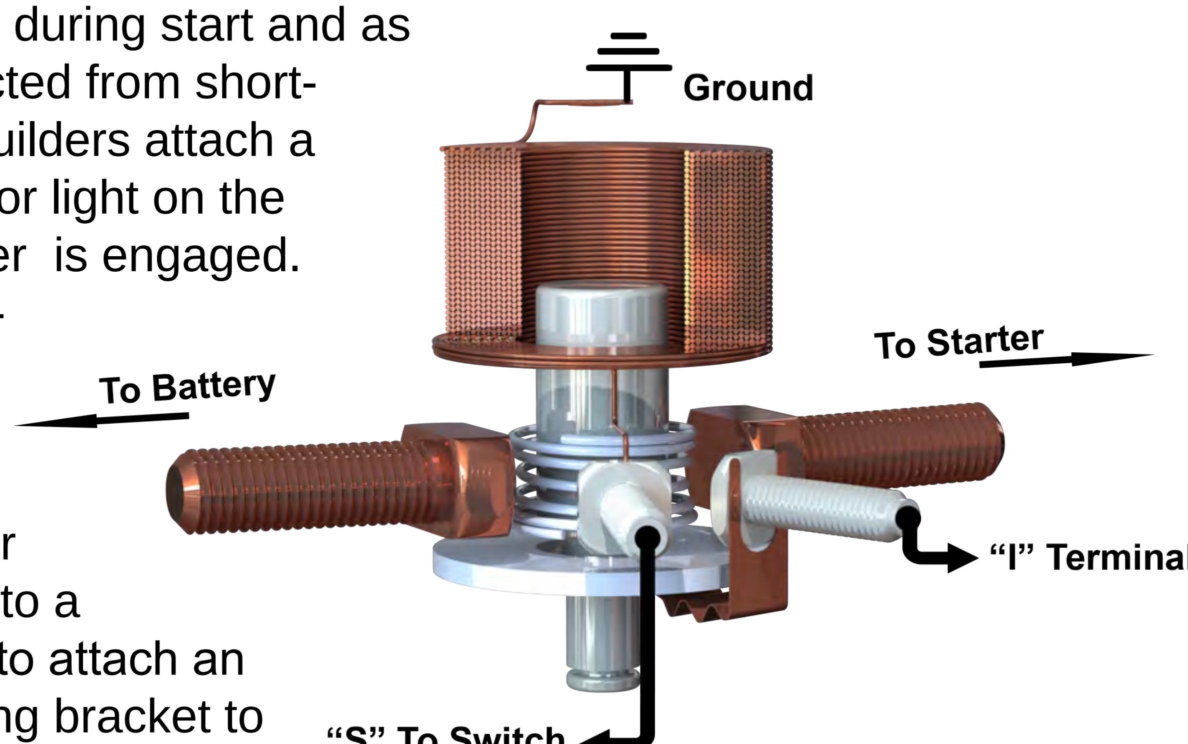

Figure: 3 Functional Components

type of starter relay that is not internally grounded to the mounting bracket. It also has two posts, but in this case, one of the small posts (S1) is for the starter switch and the other post (S2) is for a ground wire.

One of the most common problems that we see with the low cost starter relays is a failure of the coil. This and other problems are often related to vibration. The attachment of the coil wires (which are very small and delicate to start with) have a tendency to become fractured, or detached. In some cases the quality control during manufacturing is obviously to blame. We often see the coil wire wrapped around the perimeter of the starter switch post, neither welded nor soldered. Over tightening of the jam nut can sever the wire. And under tightening of the jam nut can often lead to an open connection. Testing the coil with an ohm meter is simple. Measuring the resistance from the (S) terminal to the mounting bracket (ground), should be about 4 ohms (check manufactures Spec's). While checking, tap on the relay to ensure that the internal coil connections are solid. In addition test the ground path all the way to the battery. On many of the light sport aircraft with anodized tube construction, the high resistance of the anodized tube connections are generally inadequate and require a separate ground wire. Additionally if you are troubleshooting a relay, take it off of the aircraft and give it a shake. If it sounds like a set of maracas, it probably indicates it is coming apart internally. While the relay is off the aircraft, check its operation. With a 12V battery and alligator clip jumper wires, you can actuate the solenoid. A starter relay that is functioning properly, will have a very distinct and definite "Click" as the solenoid engages. Having at starter relay that functions off the aircraft but not installed, may indicate failed wiring, or more likely, a failed starter switch. When the starter switch is disengaged there is a large reverse voltage spike, (500+ Volts) as the magnetic field of the coil collapses. This will cause arcing and pitting of the starter switch contacts eventually leading to a starter switch failure. Standard practice employs the use of a "Free-wheeling or fly-back" diode shunted from the (S) terminal to ground. With the indicator "Band" on the diode attached to the positive side of the coil (S) terminal.

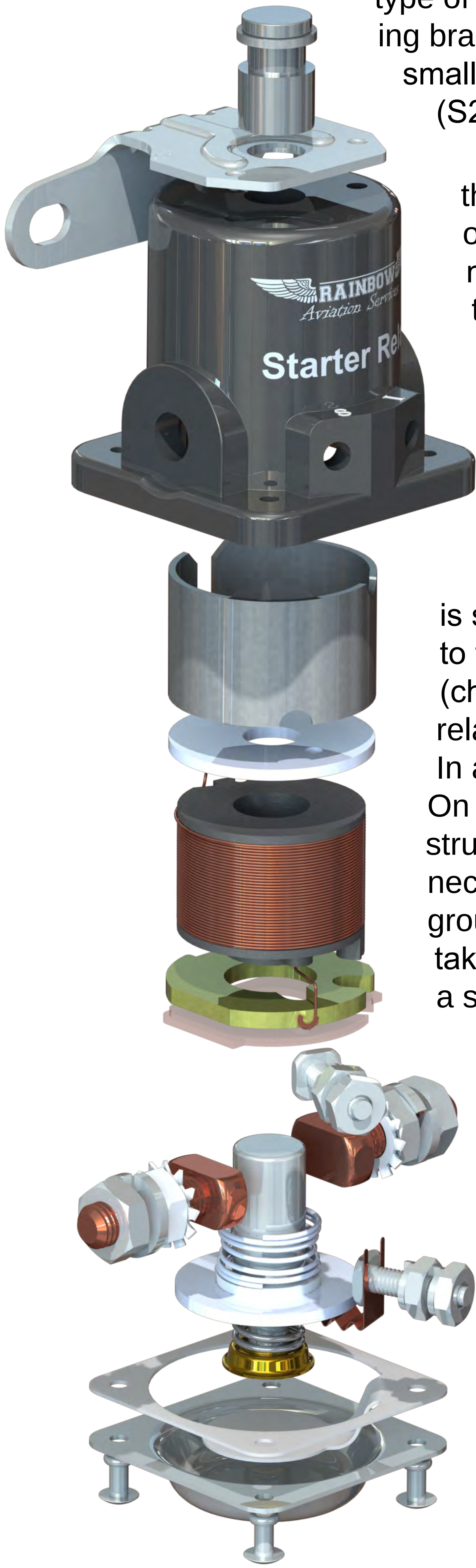

Figure: 4 Exploded View

Starter relay problems are most often fixed by simply replacing the starter relay. After all, they are not terribly expensive. However, we strongly encourage you to open up the relay to find the source of the problem. Drilling out the four rivets on the case will allow access into the inner workings. On occasion we have found simple problems that could be easily resolved and the relay reassembled with screws and lock-nuts and returned to service. However, the more important reason for disassembly, is to find the source of the failure. Having multiple failures on an aircraft is not normal. A good relay is often rated for 50,000 cycles. Yet we see multiple failures all the time with some of the low cost relays. Opening up one of these relays, and seeing the failure mode may convince you to op for a higher quality relay, a change in mounting strategy, or lead you to finding a problem unrelated to the relay in the starter, wiring or starter switch. Unlike the master switch, that has a continuous duty cycle, the starter relay is designed for an intermittent duty cycle. This, typically matching the duty cycle for a starter. For example: 10 seconds “on” maximum and minimum 60 seconds “off”, or one minute “on” maximum and minimum 6 minutes “off”. Exceeding the duty cycle of the starter or the starter relay can significantly reduce its life expectancy also.

If you are an aerobatic pilot, you probably already know the hazard of installing a starter relay in the inverted position. The center core assembly of the starter relay that engages and disengages the starter motor is held offset from the starter relay lugs with a spring. On the starter relay that we disassembled for the 3D modeling for this article, we found that the center core assembly weighed in at about 45 g. We also measured the force necessary to offset to offset the spring approximately the distance required to engage the starter relay core with the lugs and found it to be around 250 g. And although our test was very unscientific, This corresponds closely with the 5G rating on may of the starter relay spec sheets. Essentially, what this means is, on a relay mounted inverted, pulling more than 5G’s would allow the starter to engage. You can only imagine the potential damage that could be done by engaging the starter at high power settings. All aircraft should ensure that the starter is mounted in the correct orientation with the force of gravity holding the starter relay in the open position. Some aerobatic aircraft are flown with extreme forces both positive and negative, the orientation of the starter relay on these aircraft are typically mounted horizontally reducing the potential for inadvertent engagement.

A Starter relay requires about 8 volts to “pull” in the contactor core. Once engaged it will stay engaged until the voltage drops to about 3 volts. When you have a low battery, you can here the telltale clicking of the starter relay. This is the relay engaging and disengaging. As soon as the load of the starter kicks in, the voltage drop below the 3 volt holding requirement and the relay disengages. As the relay disengages the voltage returns high enough to re-engage, starting the cycle over again. Charging or jumping the battery should resolve the problem. If not, we next check your wiring and electrical connections. Next time you have your cowling off of your aircraft, you might want to check the installation. There is nothing more frustrating than being stranded at a desolate airport and not being able to get your aircraft started. However, once you have a clear understanding of how a starter relay is manufactured and operates, the process of troubleshooting becomes very easy.

With the extensive proliferation of LPD (Layered Plastic Deposition) 3-D printers, their use in experimental aircraft has begun to grow exponentially. One of the most commonly asked questions, is whether or not we can reliably produce structural components using a 3D printer. The answer is an emphatic yes. Just as with any other process or material, it has its limitations as well as its strengths. Learning to utilize the 3-D printer's strengths and work within its limitations is the key to its successful utilization.

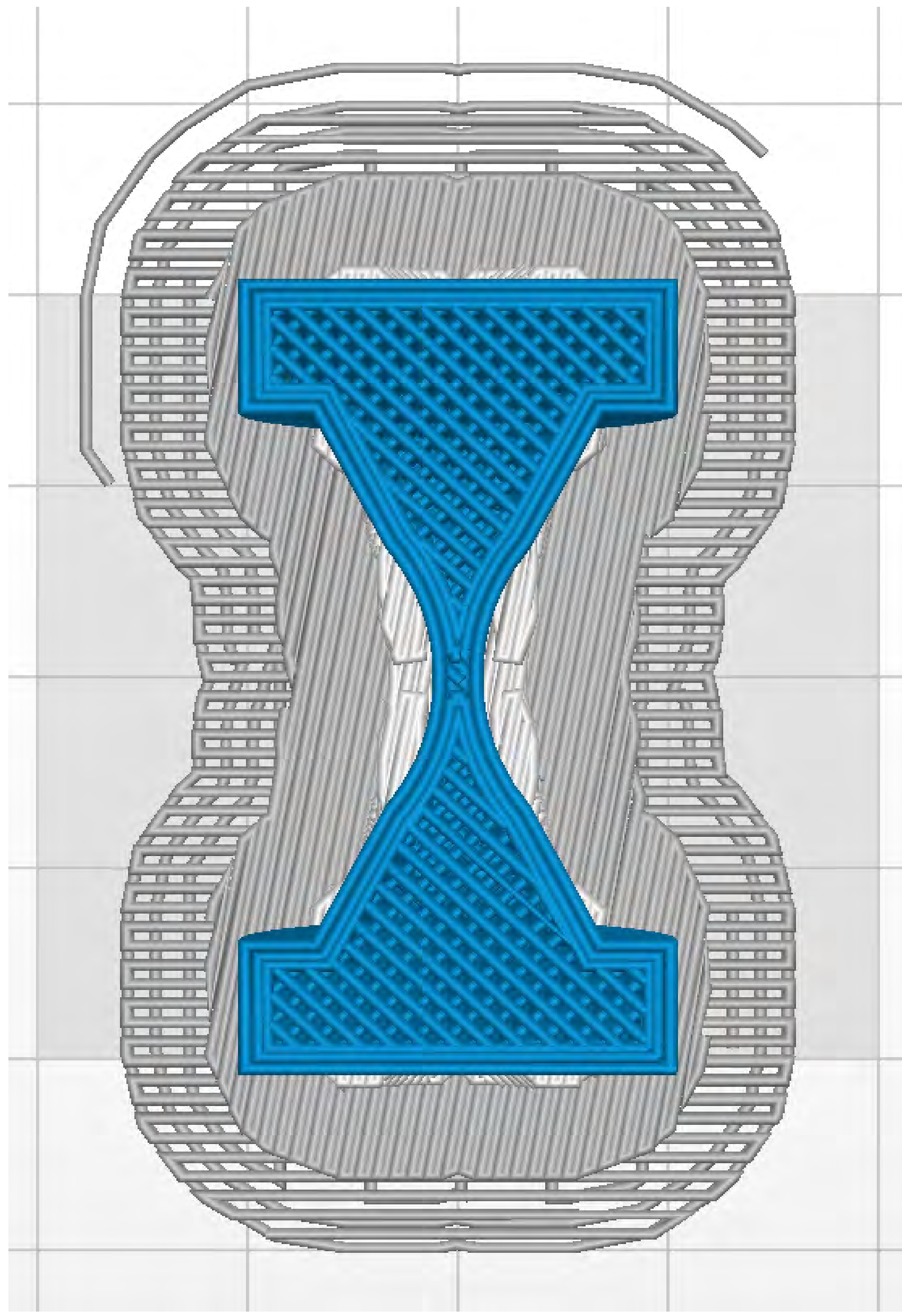
Figure: 1 LPD 3D Printing Layer

Because the LPD printers are laying down one layer of plastic at a time the resulting component has a "grain" to it. And much like wood and other materials the direction of the grain can significantly change the structural characteristics. If you have ever tried to karate chop a board, you know the trick is to strike the board along or parallel with the grain. The amount of force required to break the board across the grain can be 10 times greater than breaking the board with the grain. These long connected fibers, that grow vertically on the tree, are the secret to the trees exceptional strength. We use the same principles when we design composite structures using the long continuous fibers to carry the load throughout the structure. Similarly, the primary advantage of using forged components over cast components is to achieve higher strength by causing the internal grain of the metal structure to follow the contour of the forged component. As a result, the grain structure remains connected and contiguous throughout the entire part giving rise to exceptional structural properties. 3-D printers are no exception. With a 3-D printer, it is the long strands of plastic that are laid down in a contin-

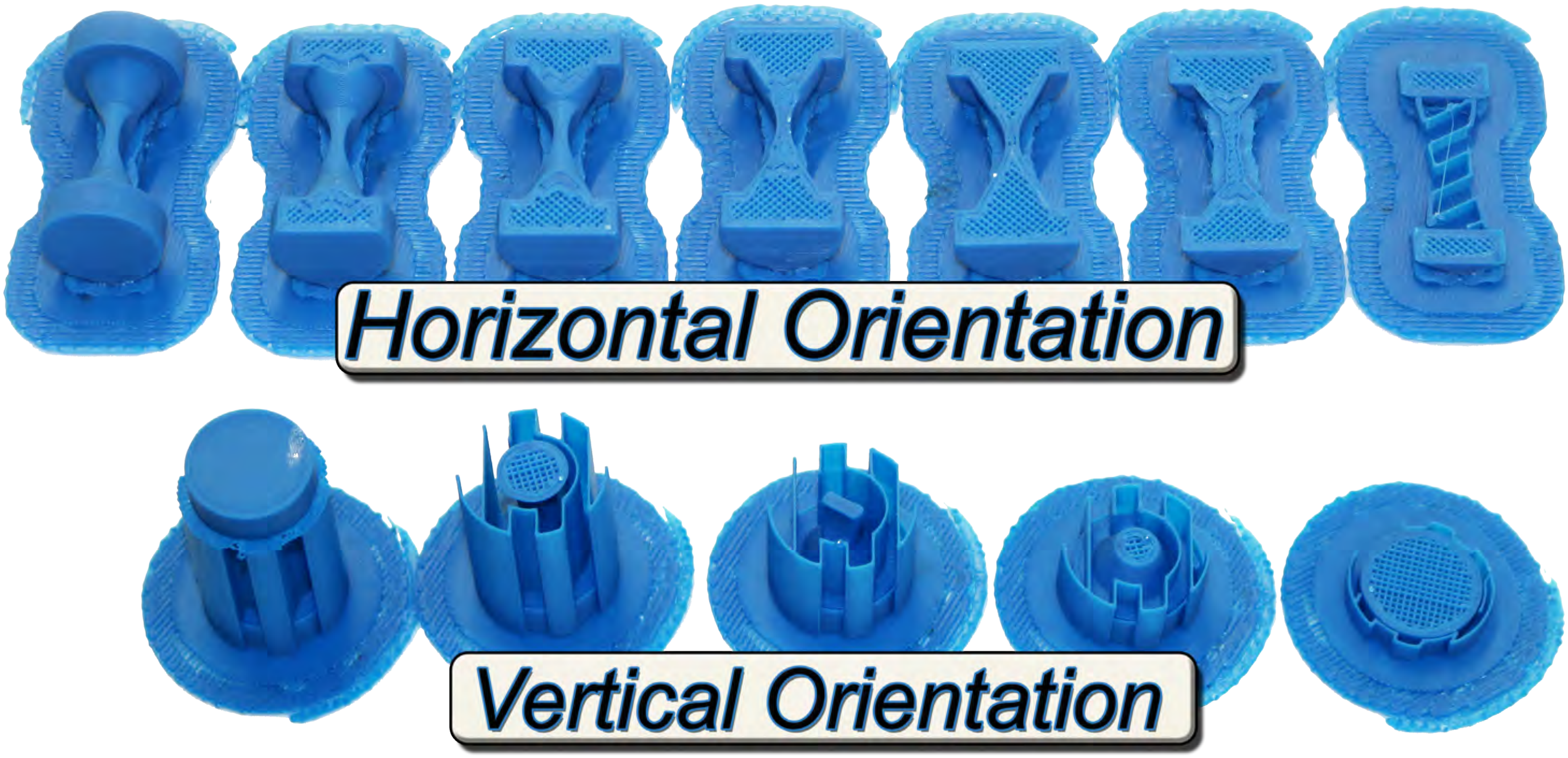

Figure: 2 *Printing "Dog Bones" Horizontal and Vertical Orientation*

uous bead that act in the same fashion. (Figure: 1) If we primarily focus our design and printing process around the concept of carrying the loads through these plastic strands, we can significantly improve the overall structural integrity of our part. Although the concept behind a 3-D printer is that we are physically melting one layer of plastic onto another making a single homogeneous part, the reality is that the breakdown of a component structurally within LPD printed part is usually related to the bonds between the individual layers of plastic.

In order to validate our hypotheses, we recently built several testing fixtures, and two different 3-D printed "dog bones". Each of the dog bones were printed both horizontally and vertically. (Figure: 2) This allowed us to test the different characteristics of each of the 3-D printed parts with respect to how the plastic is laid out. The sim-

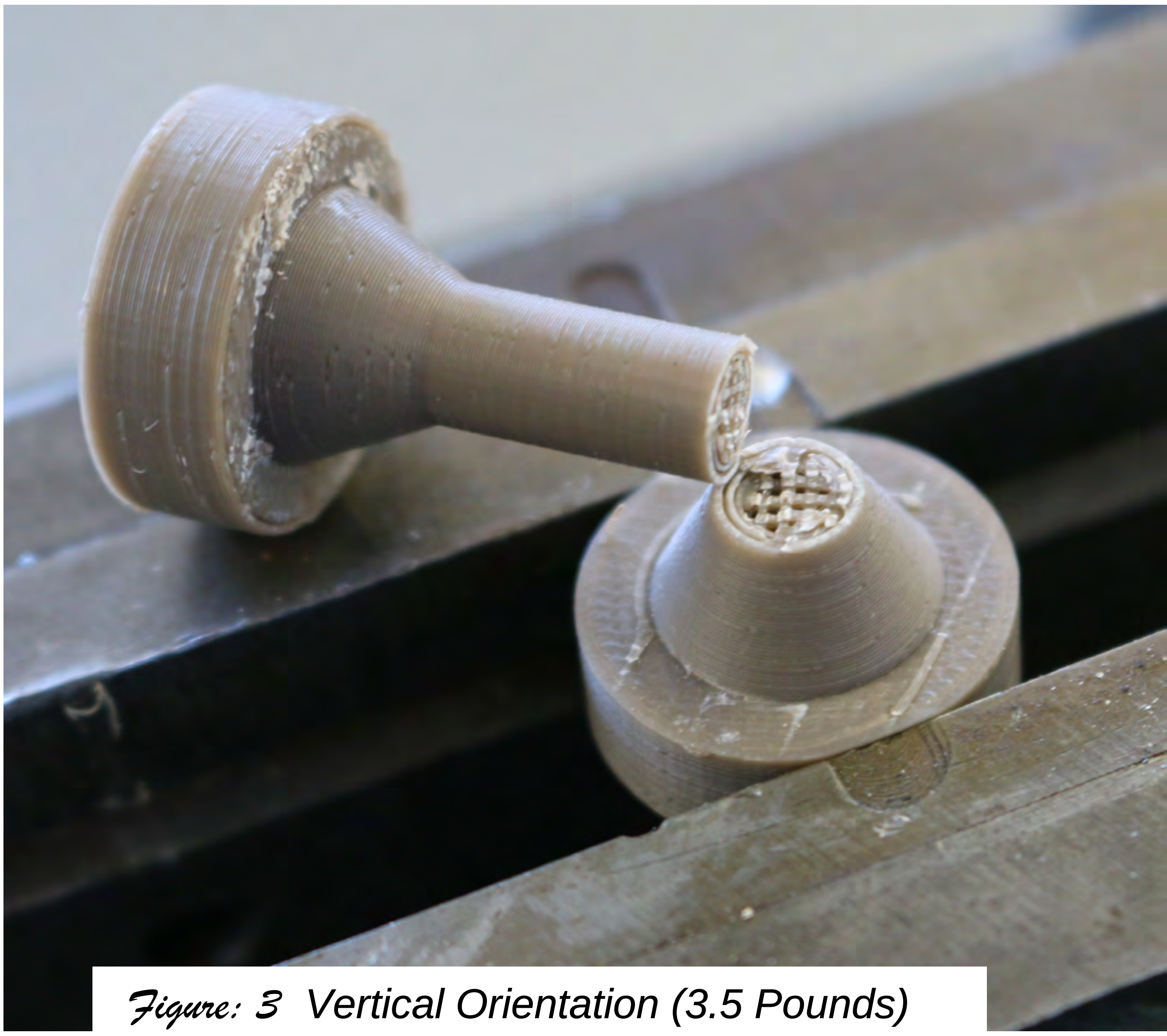

Figure: 3 *Vertical Orientation (3.5 Pounds)* plest test fixture was to use a machinist vise to hold our 3-D printed dog bone, Version 1. We then applied a horizontal load perpendicular to the vertical axes to test its breaking strength. Each test was done using a minimum of 10 identically printed dog bones in order to come up with a statistically valid average. The average breaking strength of the dog bone printed vertically (Figure: 3) was only 3.5 pounds compared to the dog bone printed horizontally (Figure: 4) which averaged 13.3 pounds. In the vertically printed part the failure mode was evident showing a simple separation and failure of the bond between layers. On the other hand, the dog bone that was printed horizontally shows signs of extreme stress in each one of the beads of plastic before the actual failure. A classic example of “with the grain” versus “across the grain”.

Figure: 4   Horizontal Orientation (13.3 Pounds)

Our second test fixture is designed to test our dog bones in tension. (Figure: 5) Shown with one half of the clamping blocks removed from either side and the test “dog bone” for clarity. Dog bone (version 2) reduced in the midsection in order to reduce the weight required to fail the component. The cross-sectional area of .01965 in.^{2} at the mid-point. The original dog bone (Version 1) while only .25” diameter in the midsection required on average 100 pounds to fail the component. This test fixture is also very simple to setup and was used to subject over 100 dog bones in different configurations to load testing. The upper half is secured to a hydraulic lift and the bottom half hooks up to a swivel joint attached to a steel bucket. The steel bucket is slowly filled with lead shot until the dog bone breaks. The weight of the bucket is then calculated on a digital scale to determine the total force required to separate the dog bone.

The results of our testing showed that, when loaded in tension, we could expect to see, on average, a 20% increase in load carrying capacity with HIPS plastic with a horizontally printed part when compared to a part printed in the vertical orientation. And about a 18% increase in load carrying capacity with ABS plastic oriented horizontally versus vertically. (Figure: 6) Although we were able to get fairly accurate repeatability using a standard protocol for our tests, the primary purpose of the tests was simply to achieve a comparative analysis between printing orientations, different materials, and for different post processing procedures.

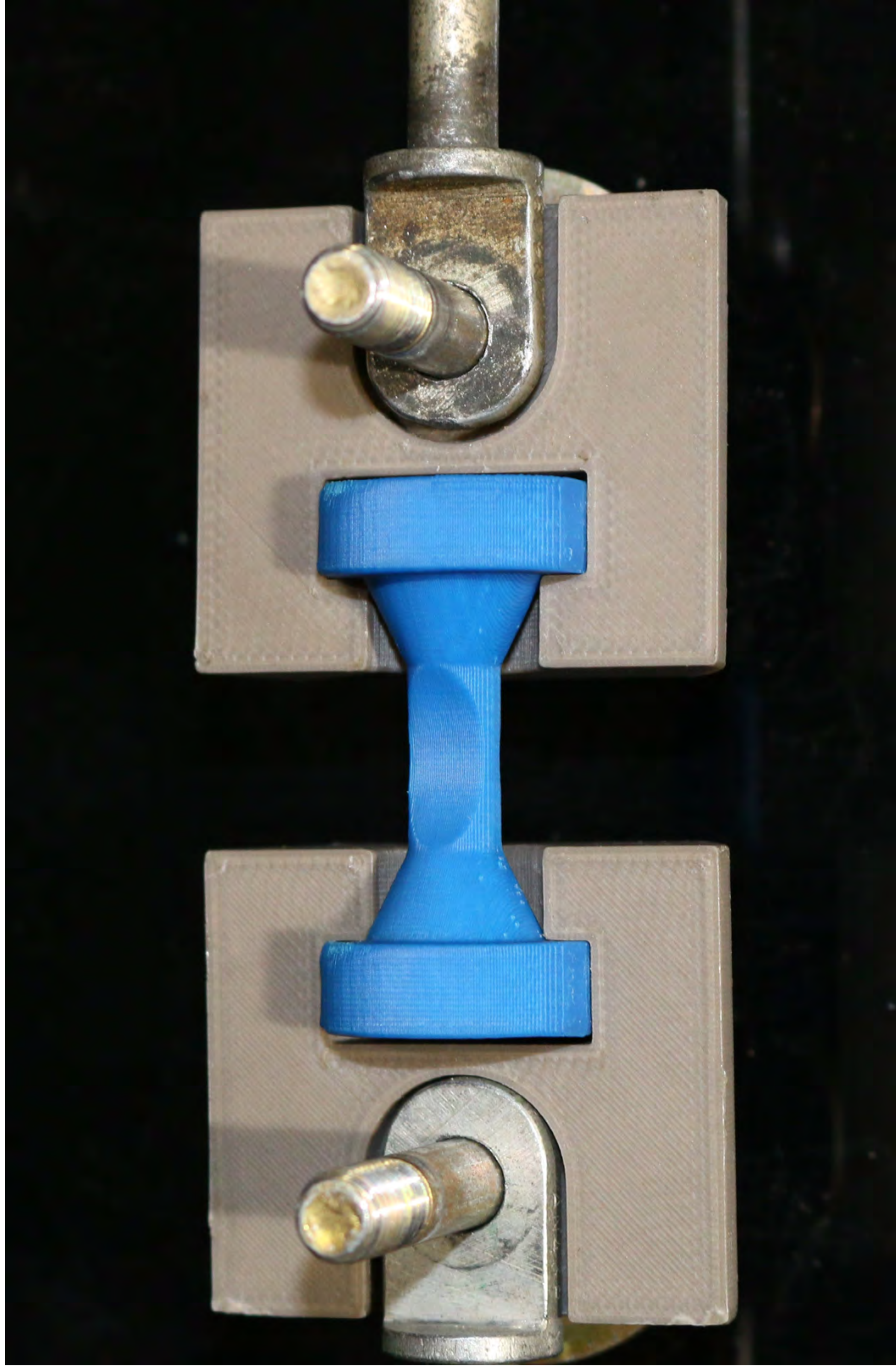

Figure: 5 Tension Testing Fixture

In our shop, we typically print with three different types of plastics: ABS (Acrylonitrile Butadiene Styrene), HIPS (High Impact Polystyrene), and Z-Ultrat, a Zotrax proprietary form of ABS (Acrylonitrile Butadiene Styrene Terpolymer). Each of these materials have characteristics that we can leverage and attributes that will enhance each of our design purposes. We generally use HIPS for printing larger parts. (Figure: 7) One of the characteristics of HIPS is its low shrinkage. When using other types of material, like ABS for printing large parts, it can often be difficult to keep the edges from shrinking and curling up, detaching themselves from the build platform. HIPS is much more friendly when making larger parts. Additionally, we use HIPS in areas where we need resistance to solvents and acetone. The use of Z-Ultrat is similar to ABS plastic but provides for a much cleaner high quality print. And, like ABS, has many options for post-processing.

The most cost effective materials is ABS, making it particularly adept at developing low-cost prototype parts. ABS also lends itself very well to many different types of post-processing procedures. Post-processing is any type of treatment after the 3-D printed part has been printed. There are many different types of post processing procedures that we can use to enhance, the aesthetics, the strength, or utility of the 3-D printed parts. In (Part 2) of this article will explore some of the more popular post-processing procedures. We will take a look at some of the load testing results on post-processed parts as well as some very interesting and unique repair procedures for the 3-D printed parts. Once you begin to recognize the capabilities of the 3-D printer you won't be able to stop thinking of new and creative ways to use it.

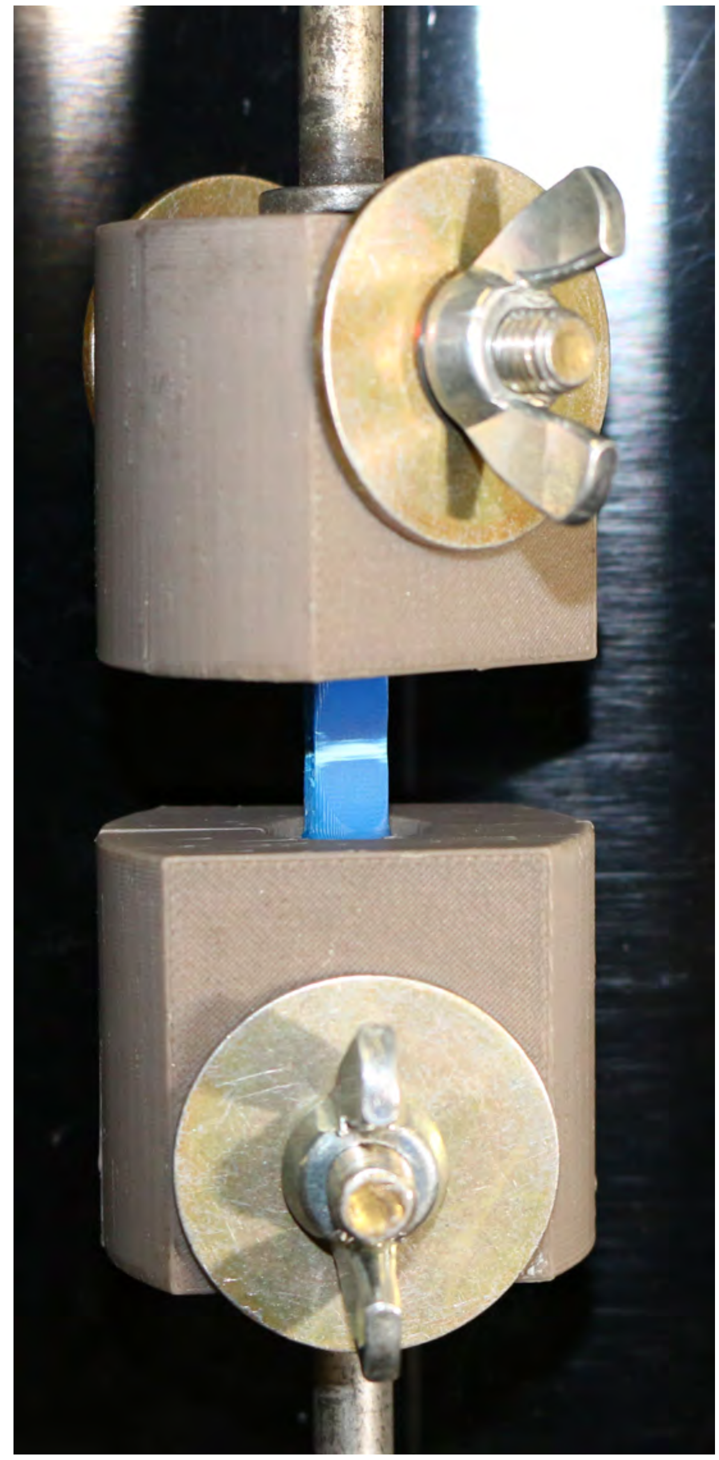

Figure: 6 ABS "Dog Bone" Horizontal Orientation, Under 57.5 pound load prior to fail-ure.

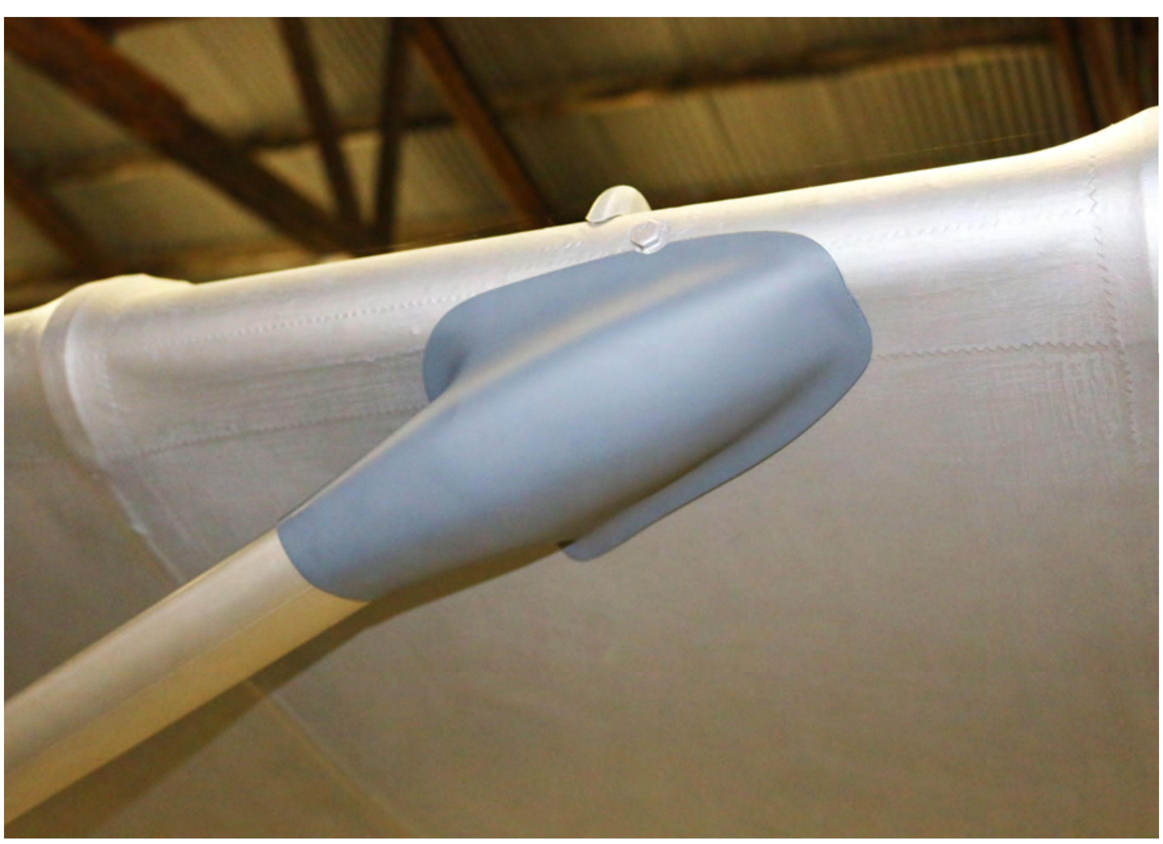

Figure: 7 Using HIPS Plastic For Printing Large Parts (EMG-6 Electric Motor Glider) Wing Strut Fairing

Carol and Brian Carpenter
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are owners of Rainbow Aviation Services in Corning, California. For more Information visit www.rainbowaviation.com

Post-processing

3-D printing with ABS plastic provides tremendous versatility when it comes to post-processing of your part. When we refer to post-processing, we are simply talking about any process that modifies the original part after it comes out of the 3-D printer. Although there are many applications that do not require any post-processing, it is generally the post-processing that converts the part from a simple 3-D printed part into a usable part on your aircraft.

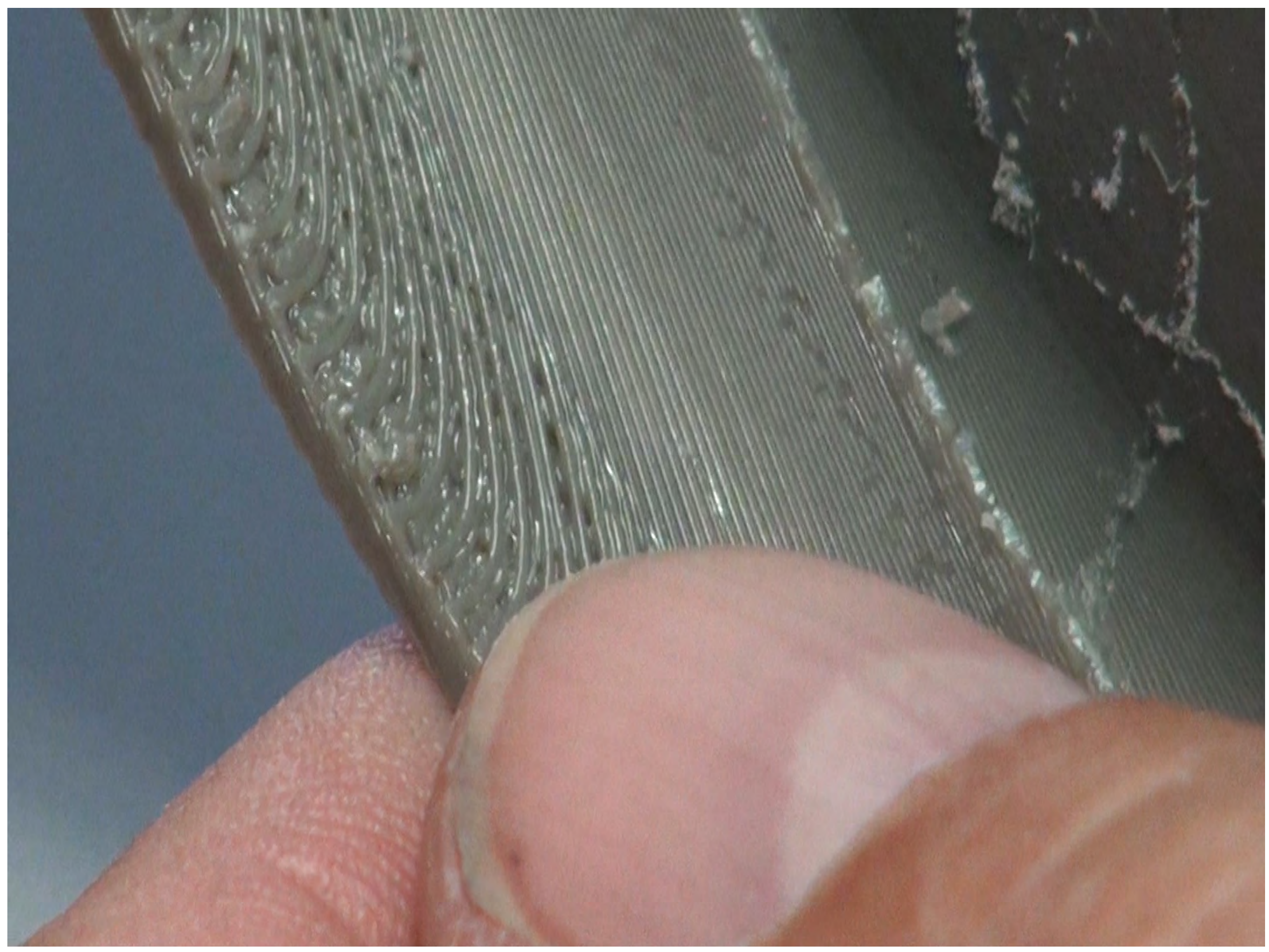

Figure: 1 Close up of Roughness in a 3D Printed Part

Acetone Treatment

One of the more popular methods that we use for post-processing ABS plastic is to the use of an acetone treatment. When 3-D printing very complex shapes with compound curves, it is inevitable that you will end up with areas within the 3-D printed structure where the slicing protocol of the 3-D printing software just has no other choice than to space the individual beads of ABS plastic further apart than would be ideal. (Figure: 1) this, inevitably, will leave a fairly rough surface. More often than not, the aesthetic properties of the parts are important so we need to smooth out these rough surfaces. The most useful technique that we use, on a regular basis, is simply to sand the part starting with 100 grit sandpaper. Then, rather than blowing off all of the sanding dust, we leave the ABS sanding particles not only on the part, but in particular the particles in the grooves and low spots on the surface of the part.(Figure: 2) We, then, take a smooth paintbrush dipped in acetone and literally paint the surface of the ABS plastic. This melts the ABS sanding particles. When done correctly, this will act as an ABS filler. The sanding particles fill the low spots and the acetone melts the high spots creating one homogeneous piece of ABS plastic. This process can be repeated over as many times as necessary in order to achieve a smooth surface. The time interval in between the application of acetone and the next sanding cycle can be literally minutes. However, we have found that waiting 10 to 15 minutes or even longer in between

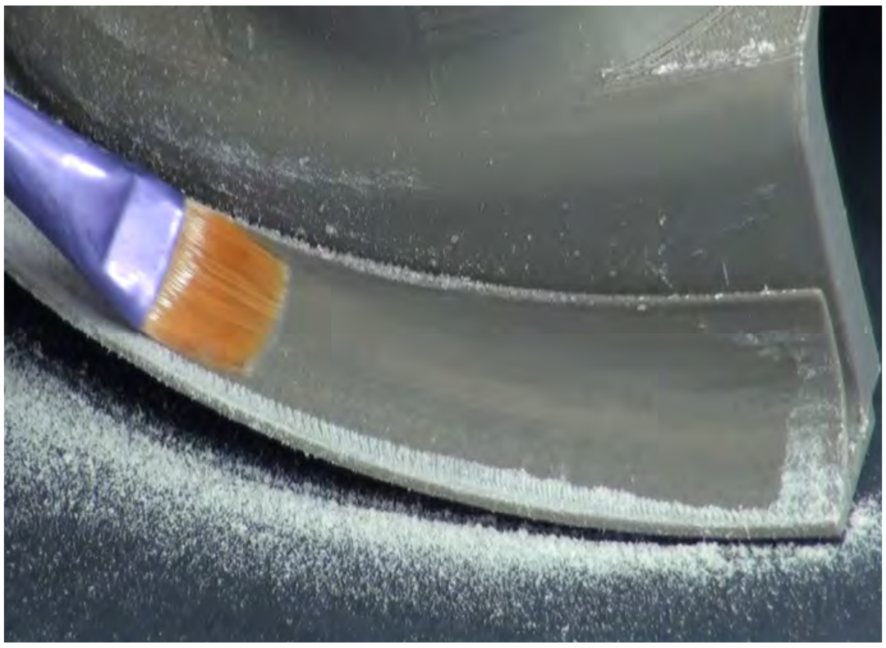

Figure: 2 *Acetone Treatment using a Paint Brush*

sanding cycles is more appropriate. Switching up to 180 or even 220 grit sandpaper for the last couple cycles can smooth the surface to the point that the part is ready for primer without any additional work. Because we are simply melting the residual sanding dust back into the part, the final outcome will appear as though no post-processing was done whatsoever.(Figure: 3)

Painting

One of the added advantages of using acetone treatment is that it softens the plastic just enough so that when you apply paint or primer to the surface the adhesion is absolutely exceptional. The solvents within the paint easily interact with the softened plastic to create a solid bond. The biggest part of any paint job is always the prep work. We have found that when using the acetone method on ABS parts, taking the stock part from of the 3-D printer and getting them into primer-ready state (Figure: 4) for paint is less work than we would typically have in prepping a piece of metal. On 3-D printed parts that have been sitting around or exposed to UV light for quite some time you may need to rejuvenate the part prior to painting or use a plastic paint design for painting plastics. These “designed for plastic” paints are pretty much a no-brainer on the 3-D printed parts. The use of a “plastic primer” usually provides a base which will work well with many other exotic paints that you may be using on your aircraft. Even on old parts we can use pretty much any of the spray can type paints if we will simply “rejuvenate” the part prior to spraying. This can be done by spraying with a light coat of acetone or even reapplying the acetone lightly with a brush. The biggest advantage achieved by a painting your ABS printed parts is that it provides good UV protection which over time can affect any plastic component. Keep in mind that before beginning any paint job on any surface, running a small sample piece through the process ahead of time to check its compatibility is highly recommended.

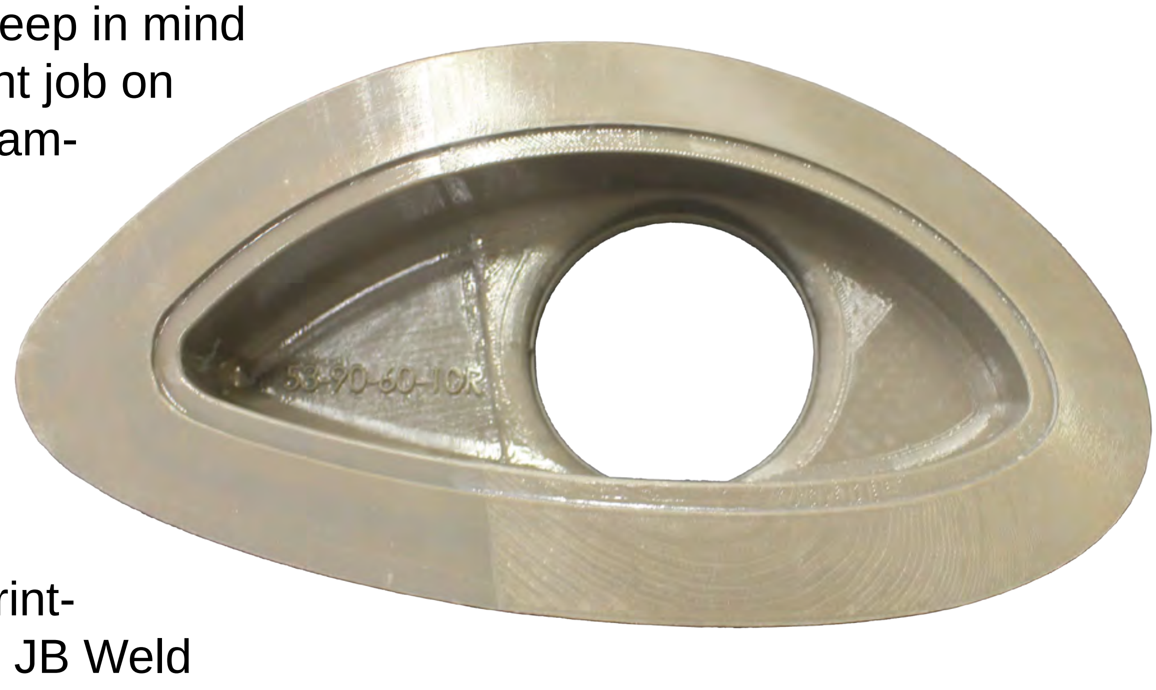

Figure: 3 *Acetone Treated Strobe Light Mount*

JB Weld

One of our favorite methods for doing repairs on 3-D printed parts is to use the 5 minute JB Weld epoxy. The 5 minute JB

Weld cures quickly, bonds very well to 3-D printed plastic parts, and sands very easily with a consistency in texture very compatible with the ABS plastic. Of course, it's dark gray color makes it useful only if you're planning to paint the part. When using the HIPS plastic JB Weld is our primary filler. This is primarily because acetone has no effect on HIPS plastic and cannot be used to melt the plastic together like we use it on ABS plastic.

Superglue

Superglue is a another medium that we've used quite extensively on all of the different types of plastic material. Applied to the sanding dust during the curing process will create a very strong joint that is also very sandable. However, we have found much better results using the hobby shop type superglue for model airplanes over the more generic superglues found at the hardware store.

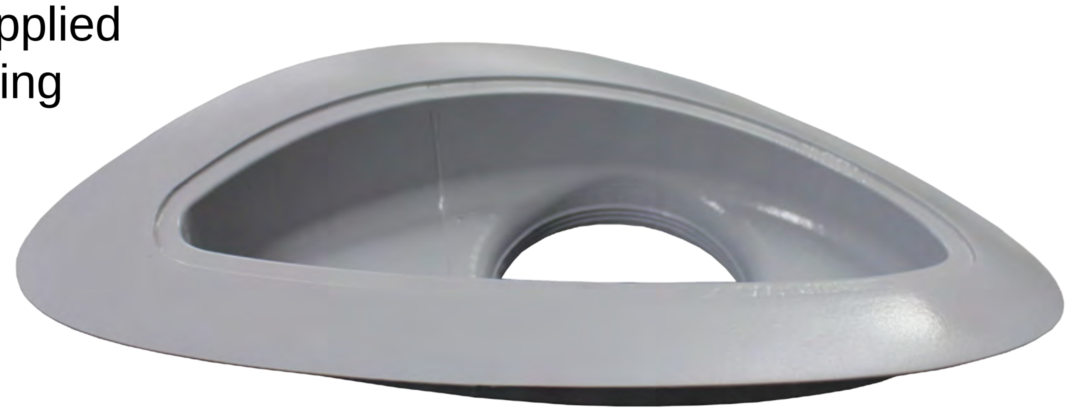

Figure: 4 Primer Applied to a 3-D Printed Part

ABS Glue

When working with ABS 3-D printed parts there is a myriad of commercially available products designed to glue ABS. Even the ABS glue use for plumbing works very well. In fact, we make ABS glue from remnants of 3-D printed support structure by simply taking the scrap ABS plastic and mixing it with acetone in a glass jar. After a few hours, you are left with a slurry of ABS plastic which can be painted onto the existing structure with a small paint brush. We will often come back on very thin wall components and apply an additional layer of ABS slurry over any areas that may need reinforcing. You can make the slurry as thick or as thin as you wish depending on your needs.

Acetone Bath.

When using the ABS type plastics, use of an acetone bath can dramatically change the aesthetics as well as physical properties of the 3-D printed part. When ABS plastic is exposed to acetone, it will melt. If we dip a 3-D printed part made from ABS into an acetone bath, it will melt the outer surface. This results in a very shiny smooth component. These parts look a lot like professionally injection molded parts after applying the acetone bath. The amount of melting of the ABS plastic will depend on the time that the part is left submerged in the acetone. From a quick dip to as much is 2 minutes, in the acetone bath, can have a dramatic effect on each part. In figure (Figure: 5) we can see the effects of leaving a part submersed in acetone for different lengths of time. From 1 second up to 15 minutes. The basic premise is that the acetone will melt the surface plastic leveling the porous 3-D printed structure leaving a flat smooth and homogeneous surface which will readily reflect light. This is the same premise used in painting an aircraft. Paint that remains wet and has a chance to level out will become smooth and shiny. Where as paint that does not level well will leave a porous or orange peel effect that can only become smooth and shiny through the process of sanding, buffing and waxing.

The use of acetone to post-process ABS plastic parts is a double-edged sword. If the acetone leaks into the internal structure of a hollow or lattice structure, the acetone will eat away at the internal structure. This can be a problem because, generally speaking, if the acetone leaks to an internal section of a 3-D printed part, it will normally seal the entry hole as it penetrates due to the melting effect of the acetone. This leaves the acetone trapped without exposure to the atmosphere. Because the acetone cannot evaporate, it will continue to propagate throughout the internal structure of the ABS part internally destroying both the aesthetic and the structural properties. One symptom that acetone has leaked into an ABS part is generally a soft spot. Often times this can be remedied by simply piercing a hole in the general area of the soft spot allowing the acetone to evaporate before the damage from melting has a chance to propagate.

We know that these post-processing procedures are very useful in creating and aesthetic appeal or in preparation for further painting. However, we had significant

Figure: 5 ABS "Dog Bone" Submersed in Acetone for The Specified Time-frame (Seconds)

concern regarding the structural aspects of undergoing this acetone bath process. As a result, we conducted an additional series of structural load tests on our dog bone samples. Although the data that we collected is too extensive for this article, we drew some general conclusions which we can share with you. The structural integrity is compromised in the near term after exposure to acetone. This would make sense because we are physically softening and melting the plastic when exposed to the acetone. As the acetone evaporates and the ABS has a chance to "cure," the strength of the individual dog bones eventually returned to the baseline strength of a dog bone not subjected to the acetone bath. With cure times over 24 hours, we did not see any change in the strength of parts subject to the acetone bath for less than 10 seconds. We did see approximately a 5% increase in strength with parts subject to the acetone bath for time frames from 10 seconds to 30 seconds. And a 5% decrease in strength at 60 seconds exponentially deteriorating to about a 40% decrease in strength at 15 minutes. Our conclusion here is that we can gain both structural improvement and aesthetic quality with a quick 15 second acetone bath. Anything over 30 seconds and we really start to see the deterioration of the ABS plastic. Even working with the parts in this state becomes difficult because they want to change shape, bend, and just dissolve which can be seen in (Figure: 5), even at 60 seconds you can see the dog bone starting to melt onto the table. At 15 minutes it is more like working with the gummy worm. We also ran tests and saw no significant structural change for parts exposed to acetone for 15 seconds or less when using cure times over 24 hours. We did periodic tests with cured parts at intervals up to 45 days.

Figure: 6 " Sparky" The EMG-6 Electric Motor Glider

All of the evaluation and testing that we've done around the use of the 3-D printer has led us to be even more encouraged with utilizing the 3-D printed parts in many different semi structural applications as well as extensively used for aesthetic purposes. We have found the 3-D printer to be an amazing tool perfectly adapted to experimental aircraft primarily because of its cost-effectiveness when it comes to prototyping small components on a one-off basis. The wide ranging post-processing procedures make the ABS plastic parts easy to work with, easy to repair, and extremely versatile for a multitude of applications. We now have over (140) 3-D printed parts that we utilize on the EMG-6 electric motor glider (Figure: 6) including the strobe light mounts that we have used for this article that double as the eyeballs for "Sparky" on the nose of the EMG-6.

Carol and Brian Carpenter are owners of Rainbow Aviation Services in Corning, California. For more Information visit www.rainbowaviation.com

Top 10 apps for the aircraft builder.

RAINBOW Aviation Services™

"There's an app for that." This overused cliché becomes more and more apropos every day. Even for the aircraft builder, we now have a virtual toolbox in our pocket that has become indispensable. We have reached the point in technology where it is now the norm for an aircraft manufacturer to publish maintenance manuals, parts manuals, and all other documentation, for that matter, in a digital format. If you've grown up on paper, the transition to digital can sometimes be difficult, but the rewards are well worth the effort.

Figure: 1 PDF Reader

#1 The PDF Reader App:(Figure: 1) The Rotax manuals, for example, consists of literally thousands of pages spanning more than a dozen different manuals. The ability to use a search function on a 500-page manual can really speed up the process of locating the information that you're looking for. In our shop, we have a library of aircraft maintenance manuals accumulated over the last 40 years. This easily encompasses four entire bookshelves from the floor to the ceiling. One of the distinguishing characteristics of our library is that, except for a small portion of the books, it now mostly takes up space and collects dust. The ability to research up-to-date and current information on each aircraft and engine makes the use of paper manuals virtually obsolete. The tedious job of doing manual revisions is long gone. Two minutes of downloading the most current version of the PDF for the applicable application brings everything up-to-date. And having it at your fingertips while you're away from

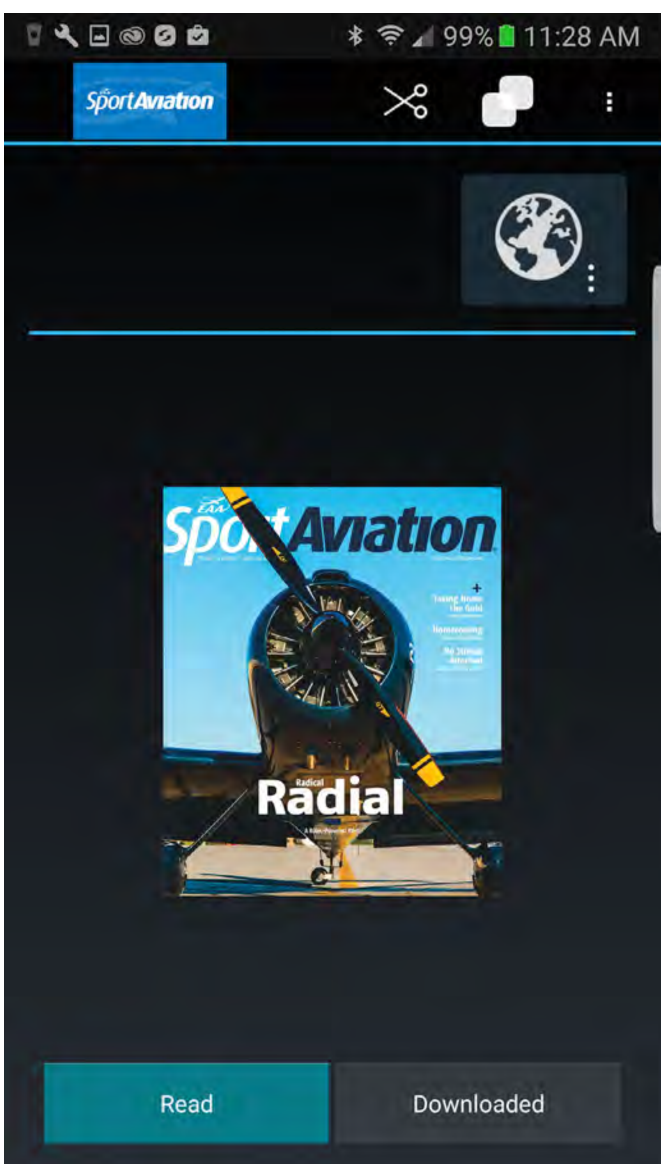

Figure: 2 Sport Aviation App

Figure: 3 Camera App

the shop, or stuck up underneath the instrument panel of an airplane, or at the far end of the ramp will boost your productivity to an entirely new level.

#2 Sport Aviation Magazine App:(Figure: 2) Although we can't wait for our big glossy Sport Aviation magazine to show up every month, we often don't have time, right then and there, to read through each of the articles. For example, if you travel like we do on a fairly regular basis, there's nothing better than having your copy of Sport Aviation magazine ready to read while you're sitting in the terminal waiting for your aircraft to arrive. You can even download all of the past issues and easily have enough reading material for that 10-hour flight that you're so looking forward to.

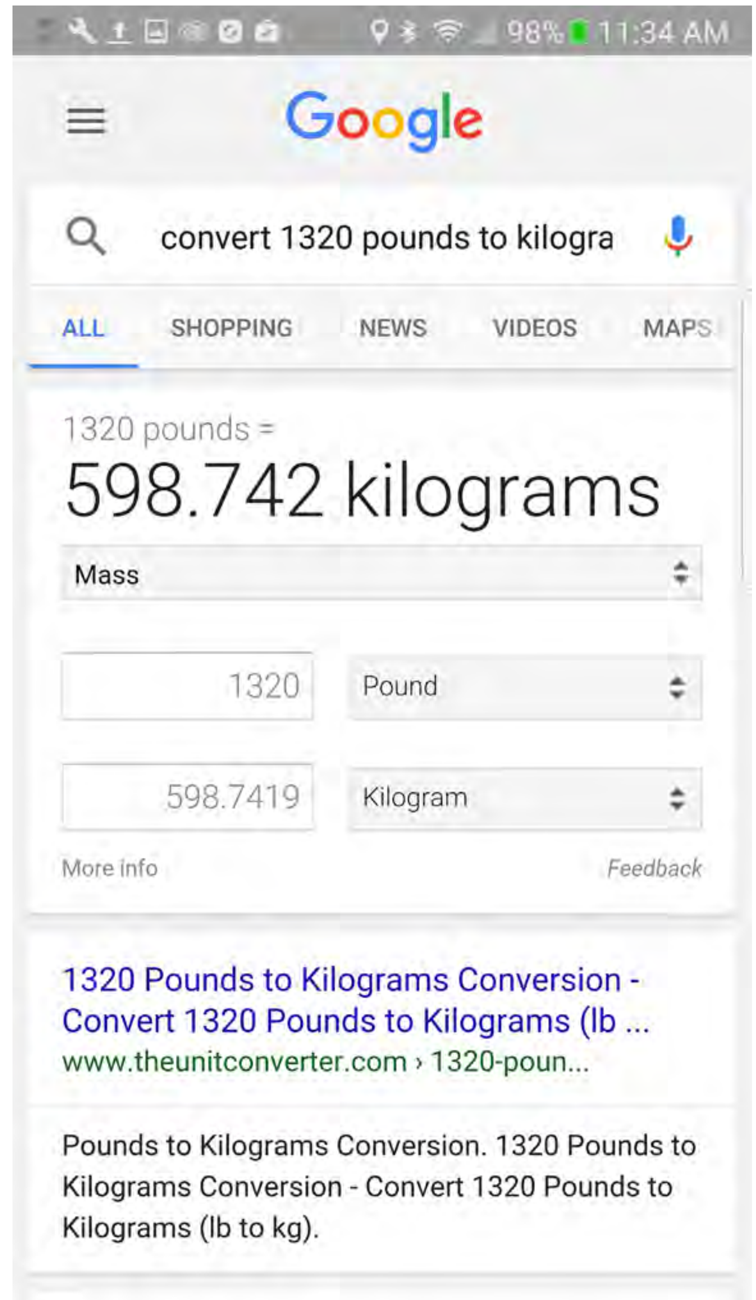

Figure: 4 Google

#3 Camera App:(Figure: 3) Another one of the most frequently used apps which we find invaluable is, of course, the camera app. The ability to take high quality pictures or video has completely change the way that our shop operates. We are able to work virtually with a customer hundreds of miles away keeping them up-to-date with progress reports and visual aids to help them understand what's happening with their aircraft. Creating a visual diary through pictures of your aircraft build not only provides a great memento but also serves the dual purpose of providing the builder's log to substantiate the 51% rule when applying for your airworthiness certificate on your amateur built aircraft. If you're planning on restoring an old aircraft, the camera is your best friend. Taking pictures along the way as you disassemble the aircraft will be of great assistance when it comes time to put it back together. This is especially true with some of the older aircraft where manuals or drawings are sparse. We would never consider an engine change without first creating a visual record of the entire engine compartment. If you've ever put an engine back into an airplane, but it was two years later, you'll be amazed at the usefulness of this simple tool. We can also attest to this fact: you will never have enough pictures of

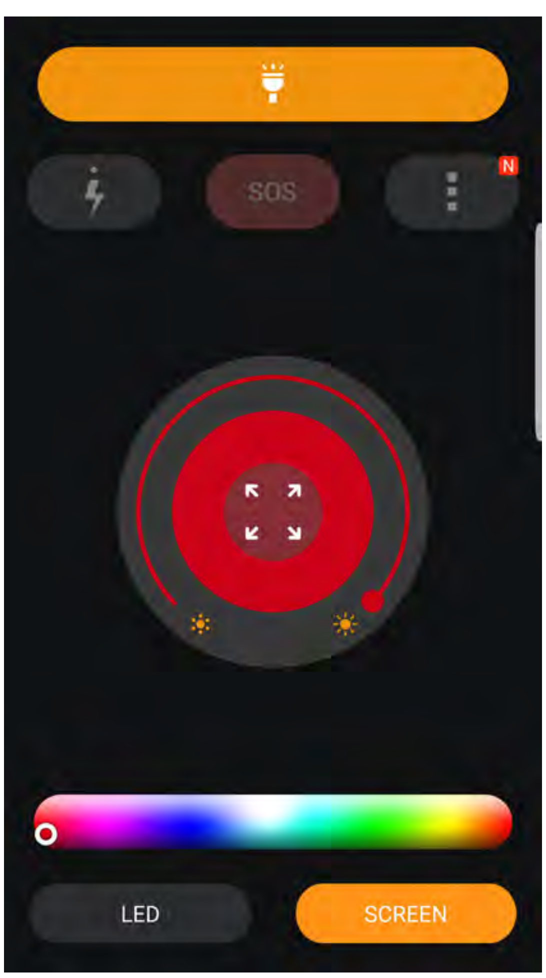

Figure: 5 Flashlight

Figure: 6 McMaster Carr

the right spot. The quality of many phone cameras now days is so great that we use the camera as an inspection aid during annual inspection. You can't get your head up into an inspection panel access hole but you can fit your camera. In the video camera mode, with the LED light turned on, it's amazing what you can see on the inside of the wing or fuselage. The clarity in the high definition video is far superior to the many borescopes that we possess. You can take the video back to your desktop and scrutinize even the smallest of details.

#4 Google:(Figure: 4) In addition to Google's amazing search engine, we are often surprised by the number of people who aren't aware of its ability to conduct any mathematical calculation as well as convert practically any unit of measure with a single touch of a button. If the phone is simply laying on the desk just say "convert 1320 pounds to kilograms." Google will respond in a voice command "1320 pounds equals 598.742 kilograms." Simultaneously displaying the answer on the screen. Give it a try, you'll be amazed at its capabilities. We even use this function to tally up the totals in our logbooks. Just read the column of numbers "1.4+1.1+.7+1.4+.9. . . etc." And Google will spit out the correct answer. If you suffer from "fat finger" syndrome, you will find this method of completing mathematical calculations on cell phone a godsend. Of course you're going to also want to download a calculator app as well. And there are literally hundreds of them to choose from. Although you may find one calculator app more to your liking, the rating system usually is a good way of vetting the really poor ones. Most of the apps provide a simple calculator with big buttons when the phone is oriented vertically and then turns into a scientific calculator with smaller buttons when rotated horizontally.

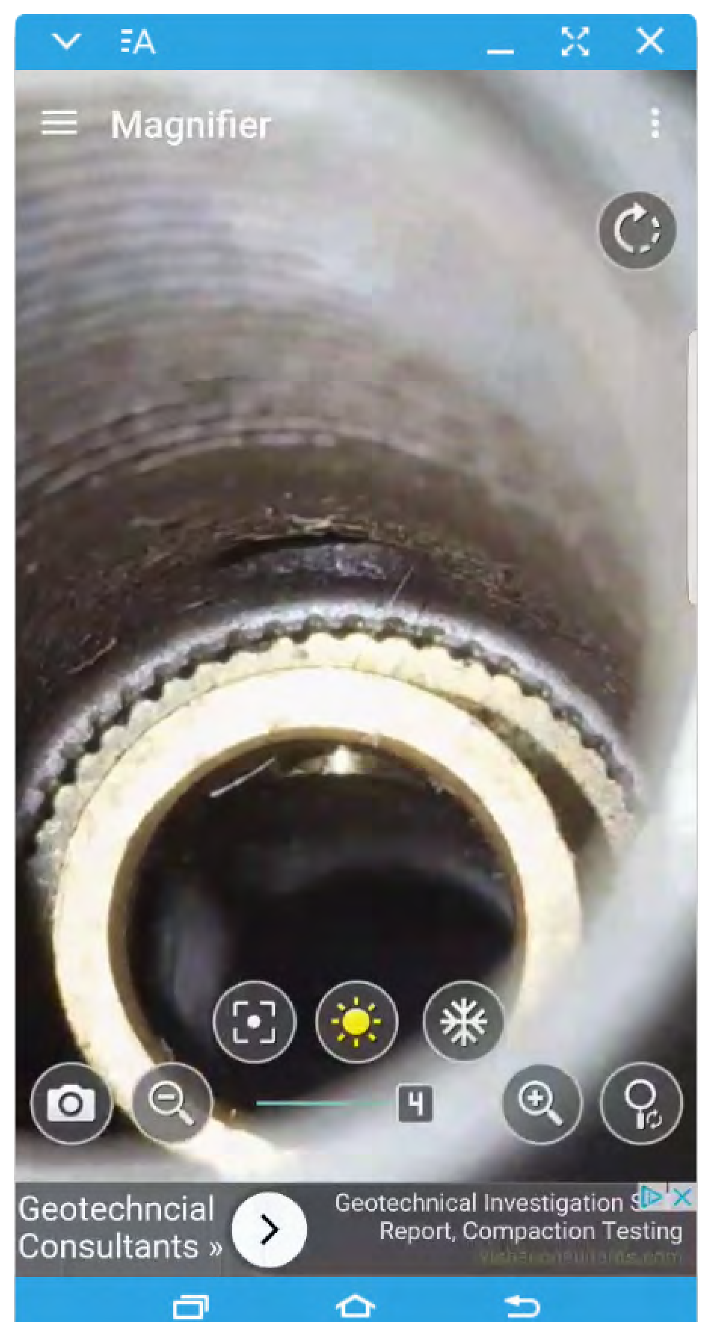

Figure: 7 Magnifier

#5 Flashlight app: (Figure: 5) Of course, if you got a cell phone, you probably already have a flashlight app. It's one of those simple features that you simply can't live without, no matter what you do. But for aircraft stuff, it is even more important. We are constantly working in areas on an aircraft where we need that extra little bit of light. Many of the apps now allow for the use of the very bright LEDs that are used in conjunction with the cameras as a very powerful flashlight. In addition, many apps allow you to select the screen as an alternate lighting source that can be use at a variety of brightness levels as well as color settings. We often will use the colored light in the cockpit at night very effectively. Using the camera LEDs provide a very bright light to work with, but will drain the battery much quicker. Whereas the screen light can be used for a much longer period of time such as in the cockpit environment.

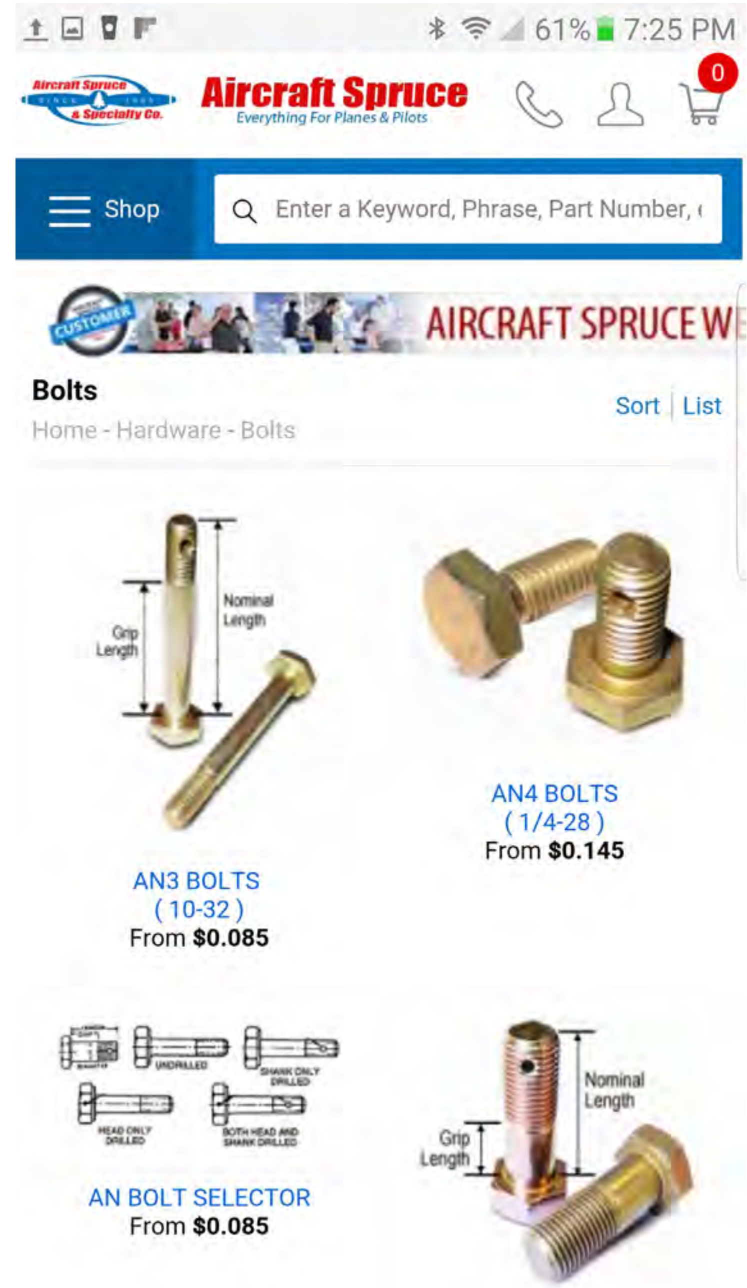

Figure: 8 Aircraft Spruce

#6 Vendor apps. More and more vendors are putting a lot of effort into their websites to make them mobile friendly. Websites like Aircraft Spruce (Figure: 6) are probably among the favorites with aircraft builders. Using the Aircraft Spruce website with a mobile device is nearly as easy as working off of your desktop. Not only ordering, but tracking your purchases and shipping. It is becoming more and more common that vendors create mobile device apps specifically to improve the shopping experience. One of our favorite suppliers is McMaster Carr. (Figure: 7) They have a mobile device specific app which is so seamless and friendly that we will often just pull out the phone to order parts rather than walk back to the office to place an order. We have the 3,952-page catalog from McMaster Carr. We've never cracked the cover.

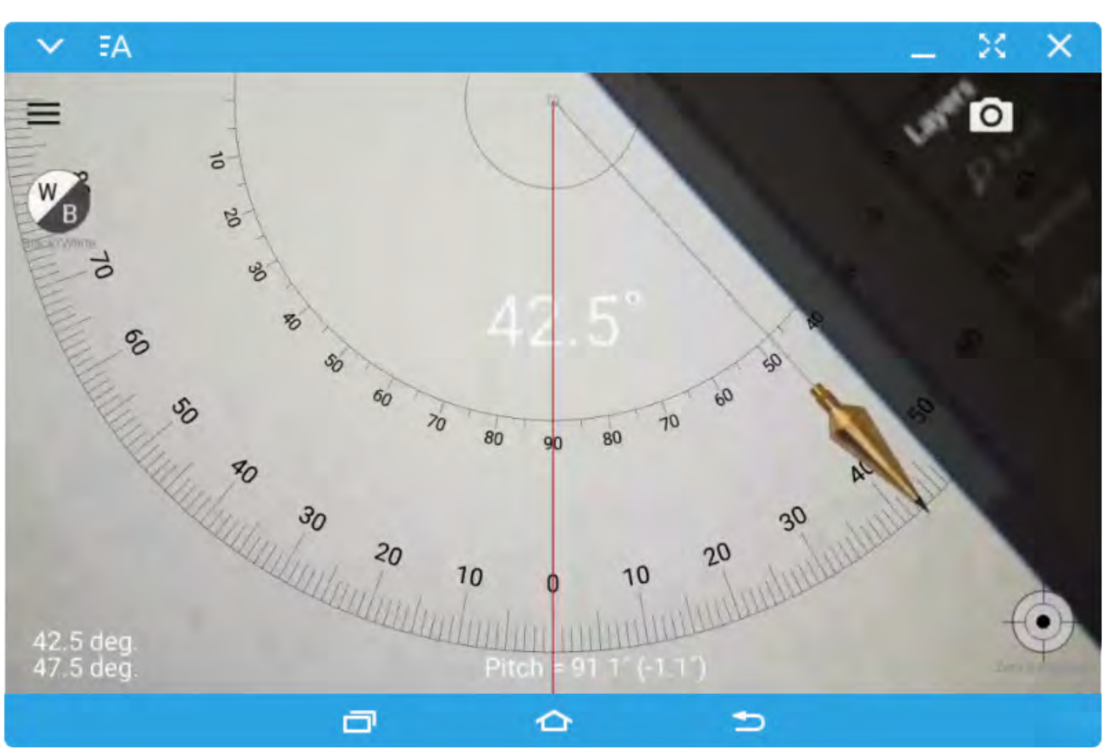

Figure: 9 Smart Level

#7 Magnifier app: (Figure: 8) The magnifier app is basically utilizing the camera technology to accomplish its mission. However, I'm surprised at how often I pop this one up to utilize. It has a couple of features that come in particularly handy in comparison to the regular camera feature. The app allows you to turn the LED light on during the operation whereas the camera typically utilizes the LED light as a flash. This allows you to use the magnifier as a lighted magnifying glass, but still has the feature of allowing you to capture images as you would with the camera feature. In the zoomed in mode, you will be surprise with the detail that you can get that you could never see with the naked eye. Just like carrying a magnifying glass around with you.

#8 Smart Tools app: This app contains a suite of different types of tools including rulers, angle measuring devices, bubble levels, tape measures, sound meters, compass, lights, mirrors, etc. The most useful of the tools in this app is the visual protractor. (Figure: 9) It utilizes the camera overlay on a plumb bob. You can use the camera to align with a specific surface and even capture the relationship with the built-in camera feature directly on the screen.

#9 Machinist apps: There are literally dozens of extremely useful applications for the average builder up through the professional machinist. One of the favorites among the students in our Light Sport Repairman Maintenance classes is the Thread Pitch app. (Figure: 10) If you're new to identifying hardware, you can simply hold a screw or bolt up against the screen and match it to the bolt to identify the thread pitch. There are a multitude of screens that allow you to not only check standard and metric threads, but tapered pipe threads as well. There are several dozen hardware apps to go along with this one. Providing a myriad of information on both SAE as well as metric hardware. The drill and tap chart app also comes in handy on a regular basis.

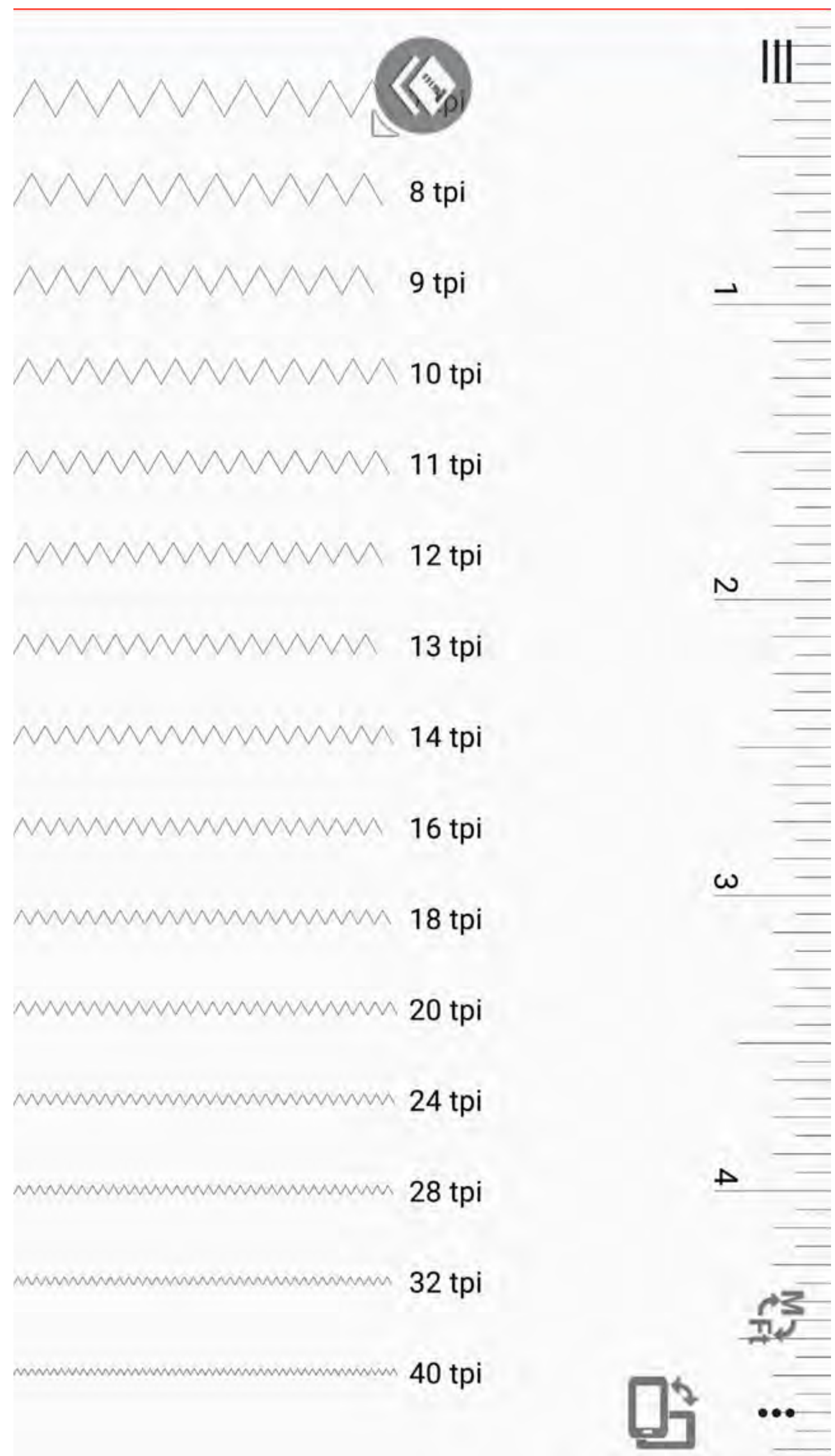

Figure: 10 Thread Pitch

#10 Vibration apps: (Figure: 11) Some of the most intriguing new apps, which we've recently been playing with, are a selection of different vibration analysis apps. The accelerometers built into the new phones are highly sensitive and extremely accurate. They are capable of measuring acceleration in all 3 axis. We can watch the vibration in real time as well as capture data over a given period of time and analyze the data later. There are several graphical output formats depending on which app you're using. We have been conducting tests to see if we can utilize the vibration app mounted in a selfie stick holder attached to the Rotax 912 during carb synchronization to supplement and validate proper carburetor synchronization. These apps promised to have very wide application in the aviation world. It will be interesting to see what other creative applications we can use the vibration analysis for.

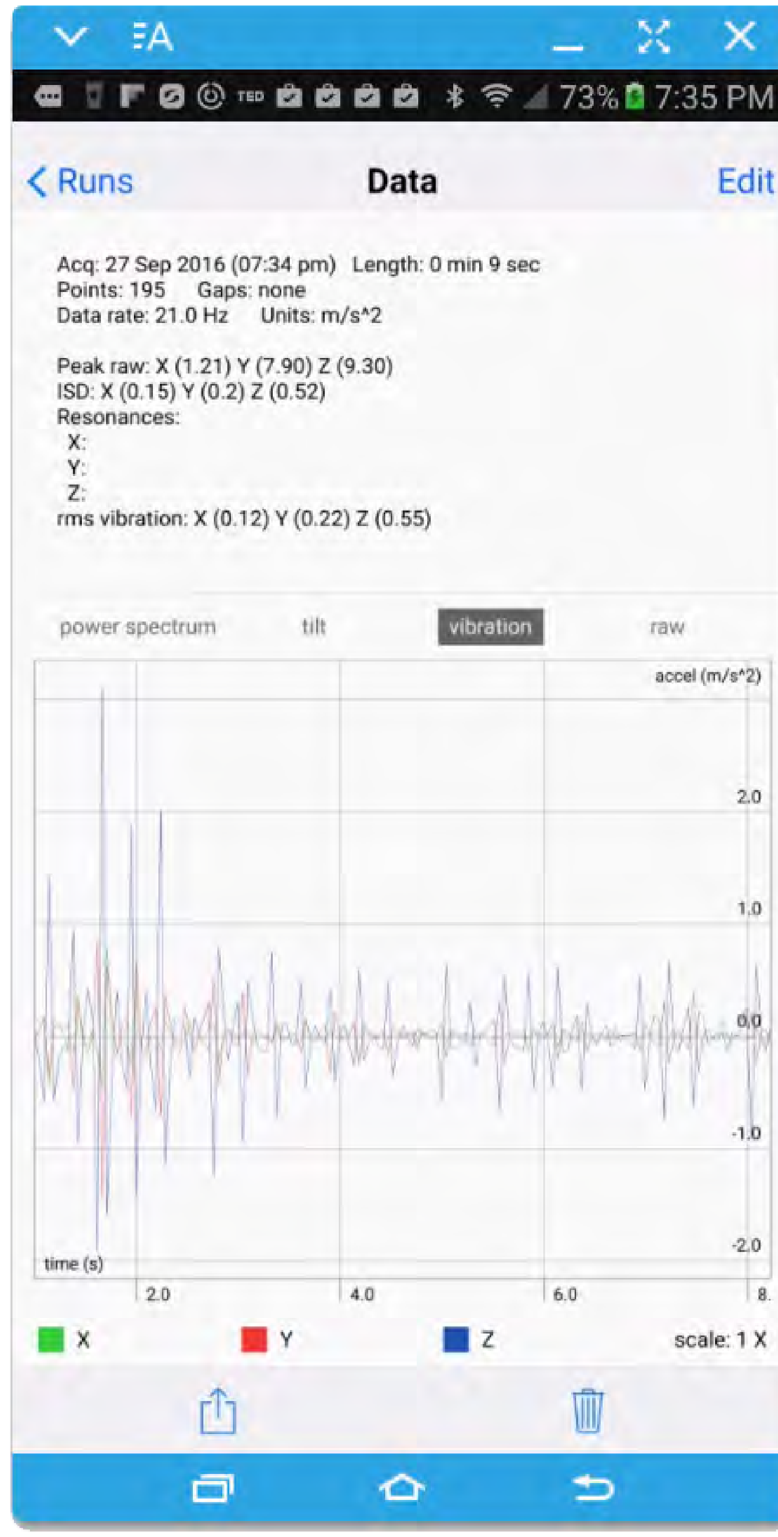

Figure: 12 Vibration App

Well, we've covered a pretty broad spectrum of different applications that we use in the aviation environment. The amazing thing is that we're just scratching the surface of what exists today. With this kind of powerhouse in our pocket, our productivity skyrockets. We encourage you to check out some of these very useful tools and see if you don't agree with our assessment. If we've come this far in the recent few years, since smart phones have been developed, imagine what we will see in the future.

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Cotter pins have been commonplace in aviation as far back as the Wright brothers. This also appears to have been the same time frame that the last update was made in regards to the subject of cotter pins. Even the FAA advisory circular (AC) 43.13-1B is unchanged from its original version and dedicates only two paragraphs to the subject: “Cotter pins are used to secure such items as bolts, screws, pins, and shafts. Their use is favored because they can be removed and installed quickly. The diameter of the cotter pins selected for any application should be the largest size that will fit consistent with the diameter of the cotter pin hole and/or the slots in the nut. Cotter pins should not be reused on aircraft.” (Par 7-127, a.) This information is followed by Par b: “To prevent injury during and after pin installation, the end of the cotter pin can be rolled and tucked.” (Par 7-127, b.) In this article, we will reference Par. b to justify a different method for installation of the venerable cotter pin.

Even as far back as the 1970’s, a dilemma concerning cotter pins was encountered by the hang gliding com-

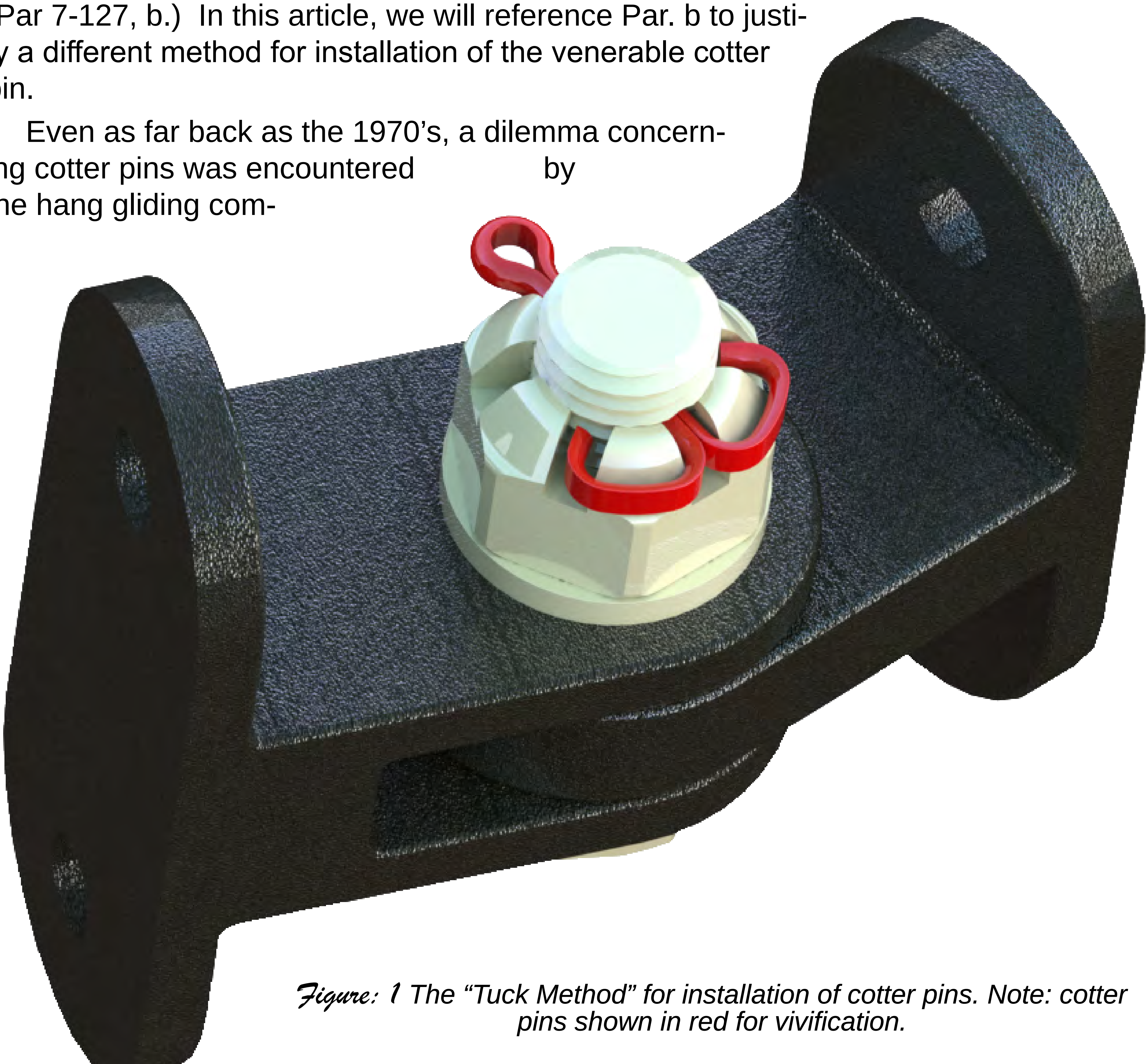


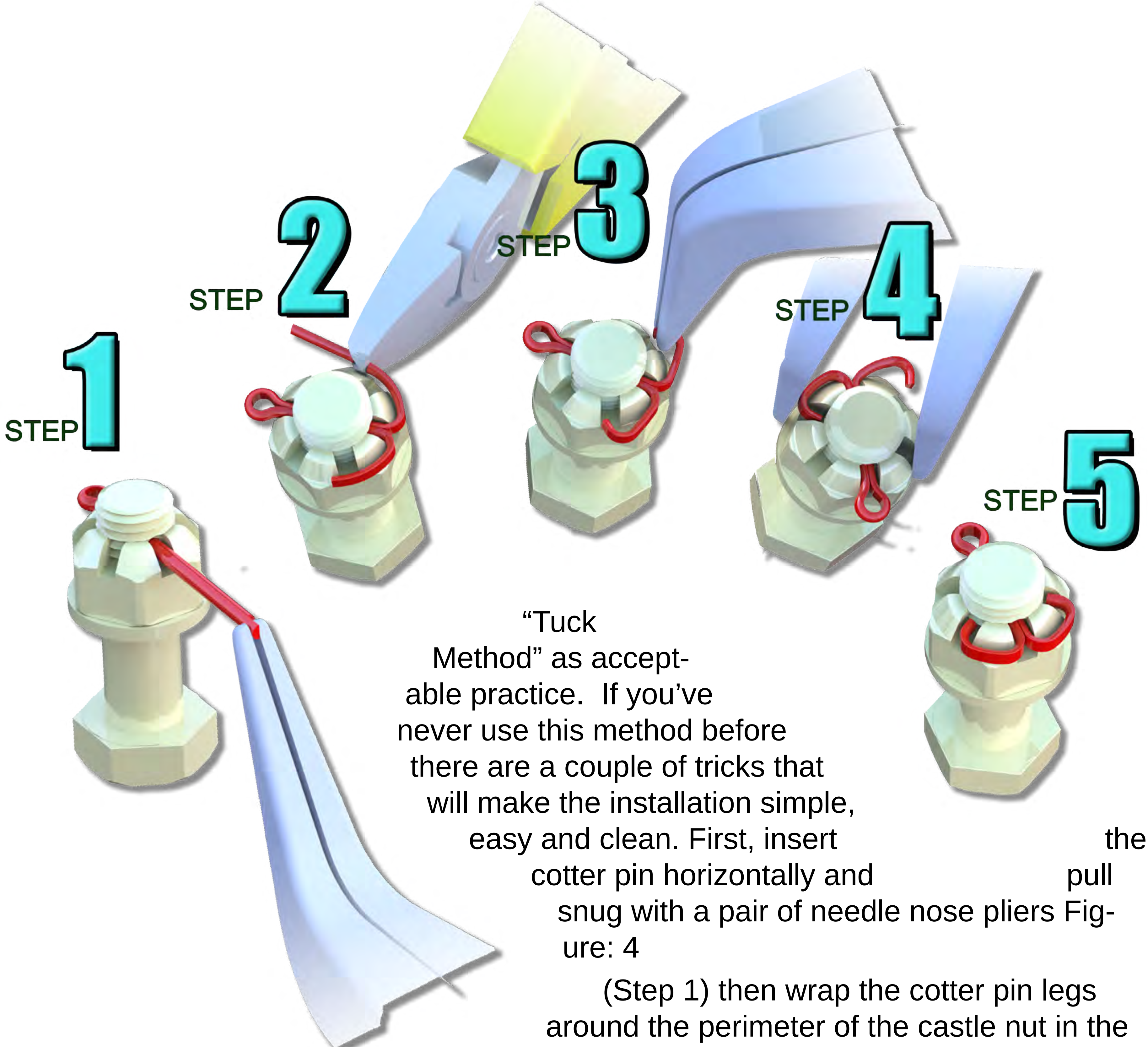
Figure: 1 The “Tuck Method” for installation of cotter pins. Note: cotter pins shown in red for vivification.

munity. For the hang glider pilots, nearly every day of flying involved "bagging and un-bagging" the wing. This was a process by which the hang glider wing, fabric, tubing, cables, and every other part was folded up and tucked together inside of a long tubular fabric bag which was zipped together. The purpose, of course, was for protecting and transporting the hang glider on top of a vehicle to and from the gliding site. One of the most disheartening, yet common occurrences, happened during the "Un-bagging" or "set-up" process. As the forward wing spars were unfolded and spread out into the typical wing configuration, the sharp, cut-off end of a cotter key would catch on the fabric causing a tear. Over the years, and out of necessity, many different methods had been developed and used to protect the fabric from these nasty little cut-off cotter pin ends. But one method rose to the top and became commonplace in the hang glider community and subsequently has become standard practice in the light sport industry today. We refer to this as the "Tuck Method" of installing a cotter pin. Figure: 1

Figure: 2 The "Standard" Cotter pin installation method. AC 43.13-1B Figure 7-6

In AC 43.13-1B chapter 7 Par.127 there are 2 methods that are referred to as acceptable methods, the standard method. Figure: 2 and the alternate method. Figure: 3 The "Tuck Method" is simply a variation on the alternate method and paragraph b provides justification for the

Figure: 3 The "Alternate" Cotter pin installation method. AC 43.13-1B Figure 7-7



"Tuck Method" as acceptable practice. If you've never use this method before there are a couple of tricks that will make the installation simple, easy and clean. First, insert the cotter pin horizontally and pull snug with a pair of needle nose pliers Figure: 4

(Step 1) then wrap the cotter pin legs around the perimeter of the castle nut in the same method that you would use in accomplishing the alternate method. Then, using a pair of diagonal cutters, cut the legs just slightly past the adjacent slot in the castle nut, say, .010"- .080" past the far side of the slot in the castle nut.

Step 2) Next, grab the end of the leg with a pair of needle nose pliers and bend the leg slightly more than 90°, while simultaneously pulling the leg away from the edge of the castle nut.

(Step 3) Now reposition your pliers and "Tuck" the bent end of each leg into the adjacent slot on the castle nut.

(Step 4) After tucking each of the two legs into the adjacent slots, you will be left with a very professional looking "tuck method" cotter pin installation.

Figure: 4 (5 steps) to complete the "Tuck Method" cotter pin Installation.

(Step 5) The two legs, which are tucked into each slot, will prevent rotation of the cotter pin and make it virtually impossible for the cut off ends to come in contact with any other object.

Several areas where the "Tuck Method" cotter pin installation may be preferred include: Control cable attachments around the rudder pedal assembly where your pant legs, socks, or shoes could become engaged with an open cotter pin. Any cotter pin installations around upholstery or insulation which may become entangled with a cotter pin end. And, in general, any place where passengers or pilot could be exposed to the cotter pin. Nothing worse than having that sharp cotter pin end stick into your skin.

Standard practices for the use and installation of cotter pins:

- Use a castle nut and cotter pin any time the nut and bolt are subject to rotation. Example, flight control hinges. Figure: 5 Use a castle nut and cotter pin where the part is intended to be removed and reinstalled on a regular basis. An example of this would be your landing gear axle nut.
- Never reuse a cotter pin.
- Use the largest diameter cotter pin which will fit consistent with the diameter of the cotter pin hole.
- A finished cotter pin installation should be tight. Loose installations can cause premature wear and failure.
- (AN380) MS24665 cadmium plated carbon steel cotter pins can be used with ambient temperatures up to 450 degrees F. (232 C.) Use in non-corrosive environments. Cadmium plated cotter pins should be used with cadmium plated bolts or nuts.

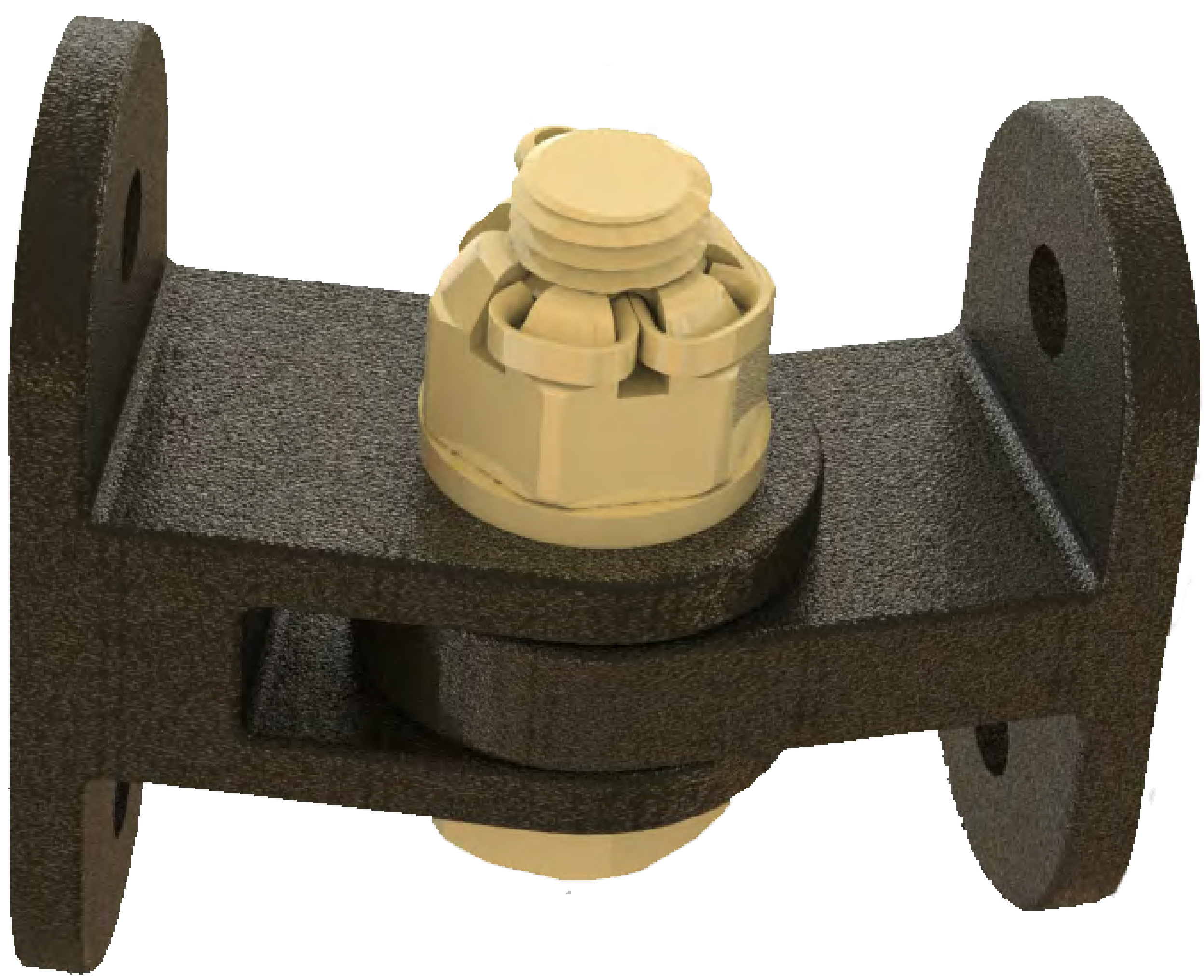
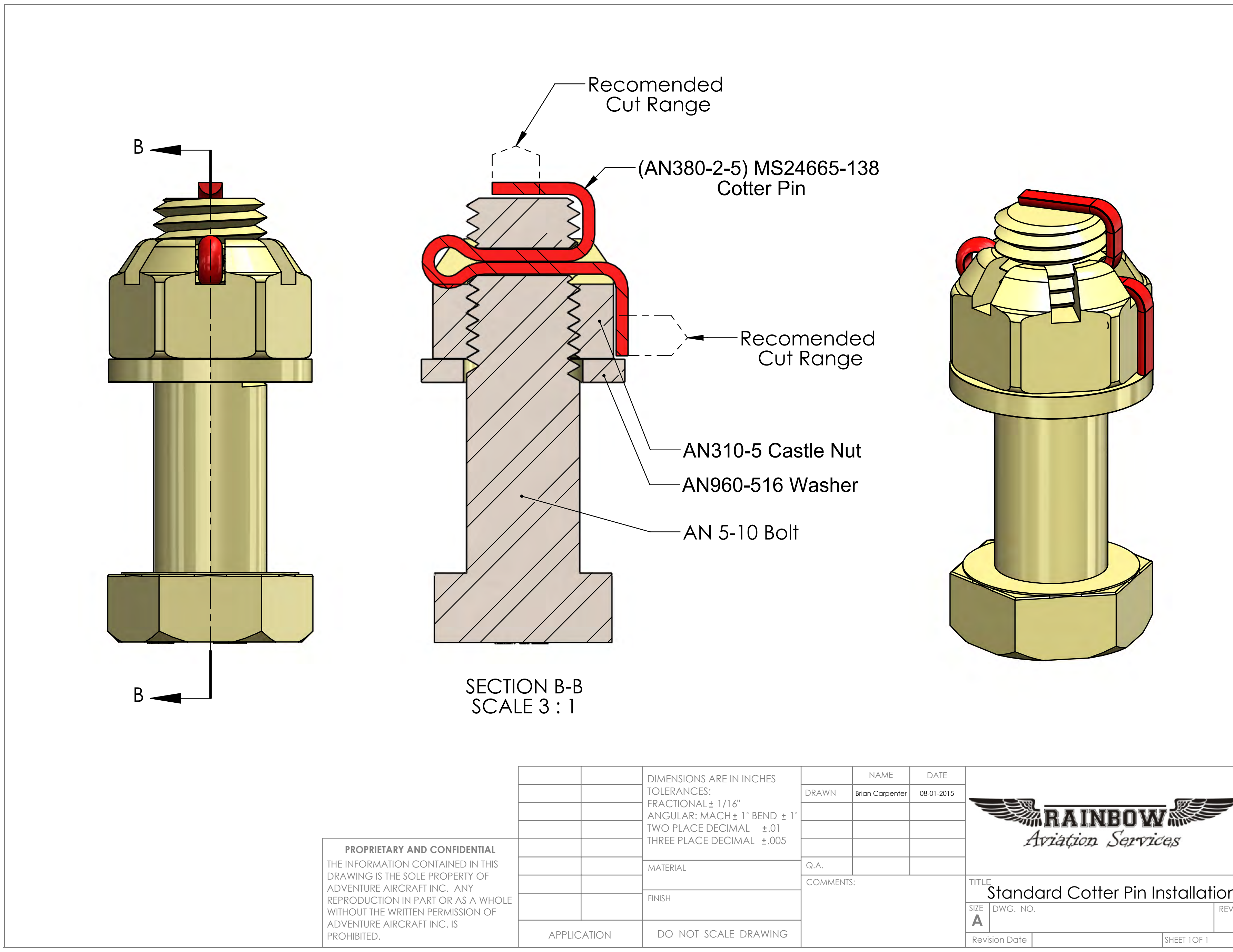


Figure: 5 *Use of a castle nut and cotter pin where the nut and bolt are subject to rotation.*

- (AN381) MS24665 corrosion resistant steel (stainless) cotter pins can be used with ambient temperatures up to 800 degrees F. (427 C.). Use corrosion resistant steel cotter pins when using corrosion resistant steel bolts or nuts. Stainless cotter pins are often used in corrosive environments. And used where there is a requirement for the nonmagnetic properties.
- Prevent FOD, (foreign object damage) keep track of the cut off ends of your cotter pins.

- The cut off ends of a standard installation should not extend beyond the bolt diameter on top leg and should not extend beyond the bottom of the nut on the lower leg. Figure: 6

In some respects, this “Tuck Method,” drawn from the hang gliding community, is analogous to the basics of aviation safety and quality. If you choose to adopt this method, it will provide a clean finish to your cotter pin installation, while providing ad-



ditional protection from possible, while likely minor, harm to your aircraft, passengers, or even yourself.

References: AC 43.13-1B chapter 7 Par.127

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Tube Cutting Templates

The classic 4130 chromoly steel welded structure has always been one of the most common building mediums to work with on experimental aircraft. This type of construction lends itself to a multitude of different types of applications and renders one of the highest strength to weight ratio manufacturing techniques, especially when it comes to fuselage assemblies. The welding of steel tube assemblies is a process that can be readily learned by just about anyone. And with current welding technologies like the TIG (tungsten inert gas) welder now coming down in price and becoming readily available to the average builder, precision welded aircraft subassemblies are no longer relegated to the professionals. (Figure: 1) Although this article is not a treatise on welding techniques, it is the primary answer to "How do I become a good welder?"

Becoming a good welder requires that you learn the principles of welding. Our recommendation, especially if you're brand new to welding, is that you simply engage in a training program. Often a community college class is your most cost-effective method of learning the skills you need. And then, of course, practice is the key to becoming proficient. As you begin the process of welding, one of the first things that you will identify is that it becomes very easy to make beautiful looking welds if everything is set up properly. Good equipment, good environment, clean materials, and, equally as important, a proper fit of the pieces of material which you're welding together. This has always been one of the most frustrating parts of making a 4130 chromoly steel fuse-

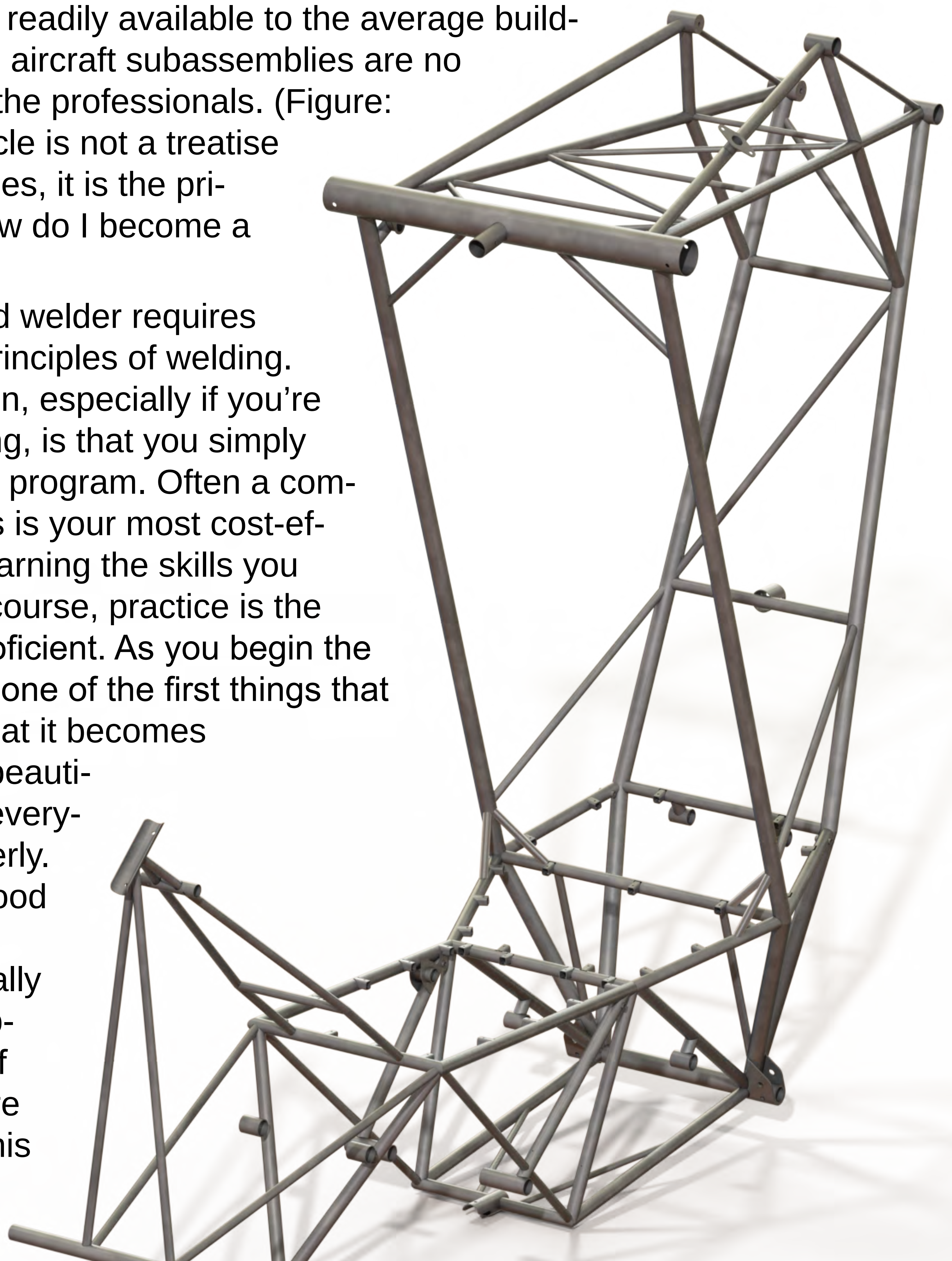

Figure: 1 4130 Chromoly Steel Frame

lage assembly. Typically, when we are working off of a set of plans, we are taking a piece of 4130 tubing, cut it to length, and then grinding each end to precisely interface with the adjacent tube. We refer to this as "coping". This process is usually a lengthy process of trial and error. We place the tube in position, then mark it, and then grind the end of the tube, refit the tube in place, check it, market and duplicate the process all over again until we have a proper fit. The process can be tedious, but if you have patience and a good eye for spatial orientation, with a little bit of practice, you can become pretty good at the process. All this being said, I've never met anyone who has welded a steel fuselage frame who has not come across the issue of fitting the tube and ending up with a fairly large gap on accident. If you've ever tried to close up that 1/4-inch gap by welding, you know that the end result isn't going to be all that pretty. Those really pretty welds, that we all admire, are primarily a result of having two pieces of metal properly prepped and with a very nice clean consistent fit against each other. The welding bead flows very seamlessly and consistently because of this close contact. Producing a beautiful weld with these conditions is a no-brainer.

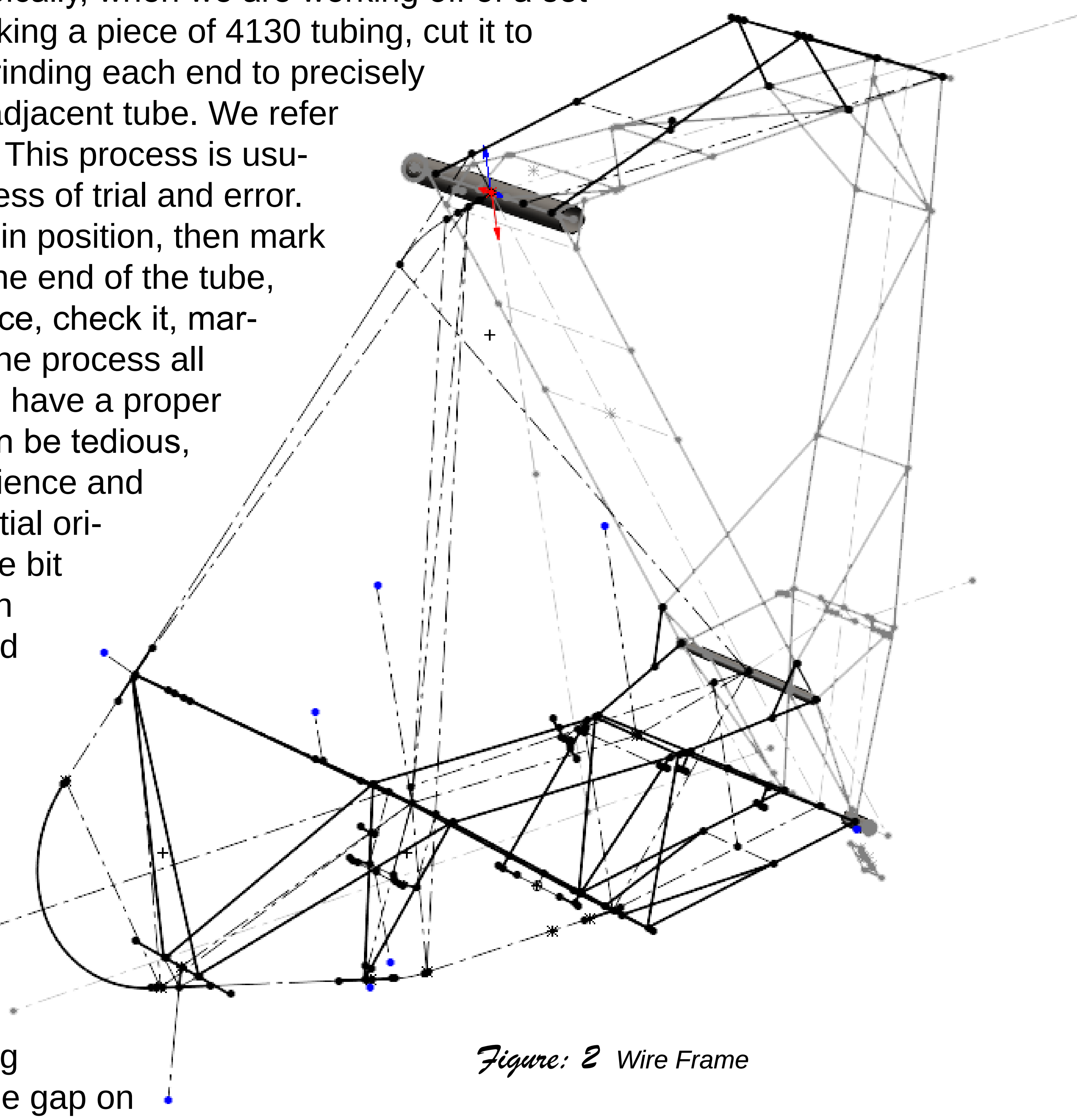

Figure: 2 Wire Frame

So the question is, if the difference between a good and a mediocre weld is the fit, how do we produce a consistently reliable good fit? The importance of a good fit is so critical that the industry in general has gone to great lengths to try and solve this age-old problem. There have been literally hundreds of CNC machines manufactured to be able to deal with exactly this problem. However, for the average homebuilder a $150,000 CNC tube cutting machine isn't exactly a good fit. And even the cheap CNC machines at $40,000 are still a ridiculous option. Those that have purchased the CNC tube cutting machines typically offer their services to precut your tubing for you using their machine. And although an aircraft manufacturer who is building a multitude of the same frames over and over can make use of these services, the price for this service to the average homebuilder is still not cost-effective. There is also a myriad of different types of tube coping machines using a drill press and a fixture to hold the tubing in place while cutting the profile with a hole saw. We, personally, own three of these. Today, they all sit in the bottom of a toolbox somewhere. The problem with all of these methods has to do with the special nature of the 4130 chromoly steel fuselage frames used in aircraft. Most of the tubing, which we're using, is thin wall tubing with a thickness of, typically, .035". Unless you are buying hole saws with about 48 teeth per inch, it is just a brutal process cutting through this thin wall steel tube. Even when working with thicker wall tubing, the cutting process can work ok, but the downside is the set up time can be quite frustrating when moving from one size tube to the next. After years of dealing with these problems, and having built a myriad of steel fuselage assemblies, we finally created a better mousetrap: tube cutting templates.

Many years ago, we started doing most of our design work using SOLIDWORKS 3D modeling software. Within the software, there is the ability to be able to generate automatic tube profiles using basic line geometry. (Figure: 2) the process is very similar to how a lot of drawings were created in the earlier days of aircraft design simply using the basic geometry as a centerline for each piece of tubing. In the SOLIDWORKS environment, we take each one of the lines and assign it a tubing profile called a "weldment". We have created a weldment profile database for each of the tube sizes which we use and can now simply select a line and assign a tube size. Building a 3D model of the frame now becomes a breeze. When you assign a weldment profile to a line it creates a tube the exact length of that line. This creates a tube longer than necessary that extends to the intersection of the lines. The next built-in feature, that is really helpful, is the "trim" tool. (Figure: 3) It allows us to cope the end of each tube to perfectly match the profile of any adjacent tubes. There are a multitude of different trim combinations that can be selected and even a selection for the gap size between the tubes. We usually work with a .005" gap when working with thin wall tubing. Each one of the tubes within a frame will require a different

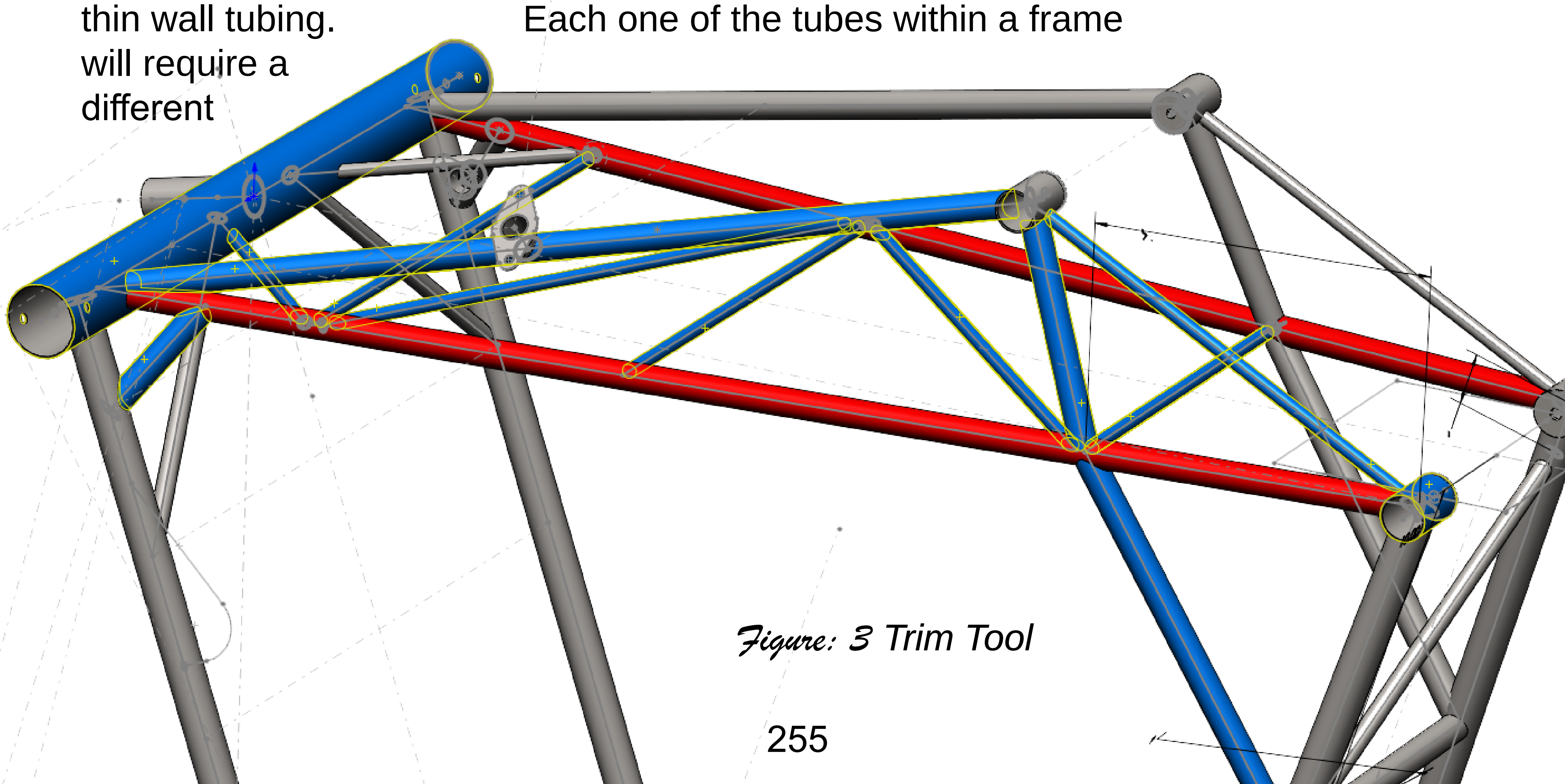

Figure: 3 Trim Tool

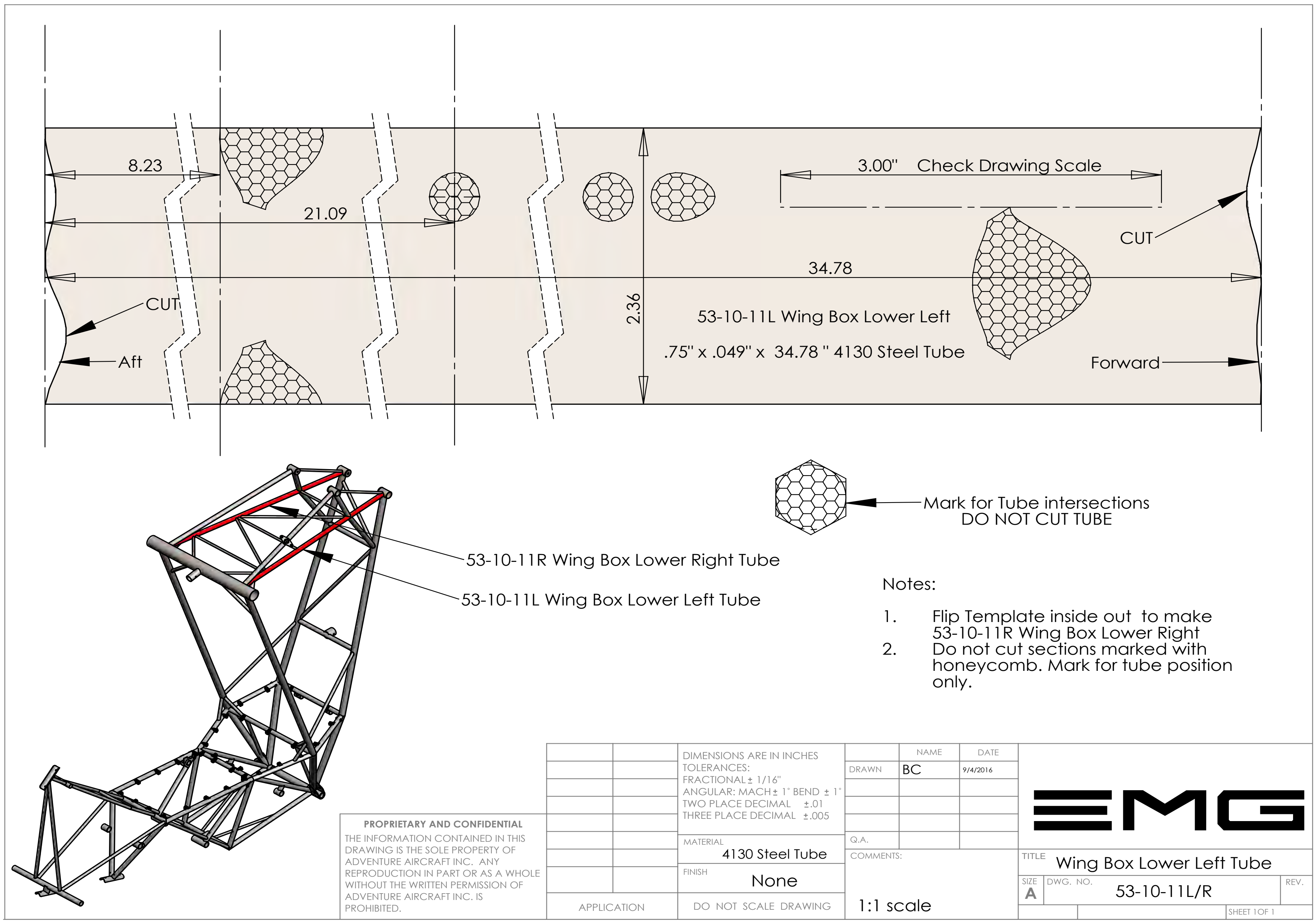

Figure: 4 Tube Marking Template

end treatment depending on the sequence of the build and other structural requirements. In addition to being able to cope the ends of each tube, we can also create intersections within the mid span of the tube. Once we have created all of the interactions with the other tubes, we can simply take the individual tube out of the frame and create its own separate part. We can then manipulate that part as its own entity. And now is where the magic really comes into play. We can take the tube profile and cut a slit down the entire length of that tube. This now becomes, rather than a tube, a curved selection which we can treat as a piece of sheet metal. SOLIDWORKS allows us to now flatten out that curved piece of sheet metal and turn it into a flat template (Figure: 4). We can then take this template and create a drawing at 100% scale which we can print out on a home computer. Once printed on a piece of paper, we have built in testing dimensions to ensure that our printer is printing truly at 100% scale. We can then cut out the template with scissors or an X-Acto knife and we have a paper template which we can wrap around the perimeter of a piece of tubing. We start with a tubing “blank”. A blank is simply a specific sized tube diameter, wall thickness, and overall length. These dimensions are labeled on the tube template. In order to mark tubes that are longer than what will fit on a standard 8.5 x 11 sheet of paper, we have created templates with breaks along the length of the drawing. This allows us to have all of the critical information on one single piece of paper. When dealing with a longer piece of tube, we start off by drawing a line down the length of the tube that we use as a reference mark to align the edge of the template. This is easily accomplished by using a piece of angle, or channel, placed directly onto the tube creating a self-aligning straight edge. (Figure: 5) We can then slide the template to predetermine dimensions specified on the template for making additional marks that can be used for identifying additional cutouts or other tube intersections. And the final tube end coping layout can be obtained by simply sliding the template to the other end of the pre-cut tube, and marking with a sharpie or magic marker. Because the tube template is slid right to the end of each end of the precut tube the amount of material necessary to grind is minimal. We have several CNC machines which we have set up in the past to cut steel tube profiles. Even in a mass production environment, where we are making twenty of the same tubes at a time, we still find the tube template process more efficient. It's great when you develop a system by where the most efficient process is also the least costly.

Figure: 5 Marking a Tube Centerline

All you need to take advantage of this system is a magic marker, and a small bench grinder. Probably the most amazing part of the tube template system is the consistent precision fit of each one of the tubes. It's so fun to weld when everything lines up perfectly. This process is so consistently accurate it makes even the newest of welders capable of making professional looking welds. On more than one occasion, we've had individuals tell us that we should be doing this system as a business plan to make templates for other aircraft manufacturers. And although our interests lie elsewhere, we believe that this could very easily become the new norm for plans built or kit planes. If you're interested in seeing more of this system, all of the plans including the tube marking templates for the EMG-6 electric motor glider, as well as some generic templates that you may be able to use on your aircraft are available free on the Adventure Aircraft website. More importantly, with EAA's new program to make SOLIDWORKS available for free to its membership, you now have the opportunity to create your own tube marking templates for the aircraft that you're working on.

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What is Twist Welding?

“Twist Welding” is a process for treating the end of a cable to prevent it from unraveling. The idea was originally shared with us by one of our students. He had been in the cable industry for nearly 30 years and had a more basic version of our technique, but didn’t have a name for it. We coined the term “Twist Welding” while developing and refining the technique. (*Figure: 1*)

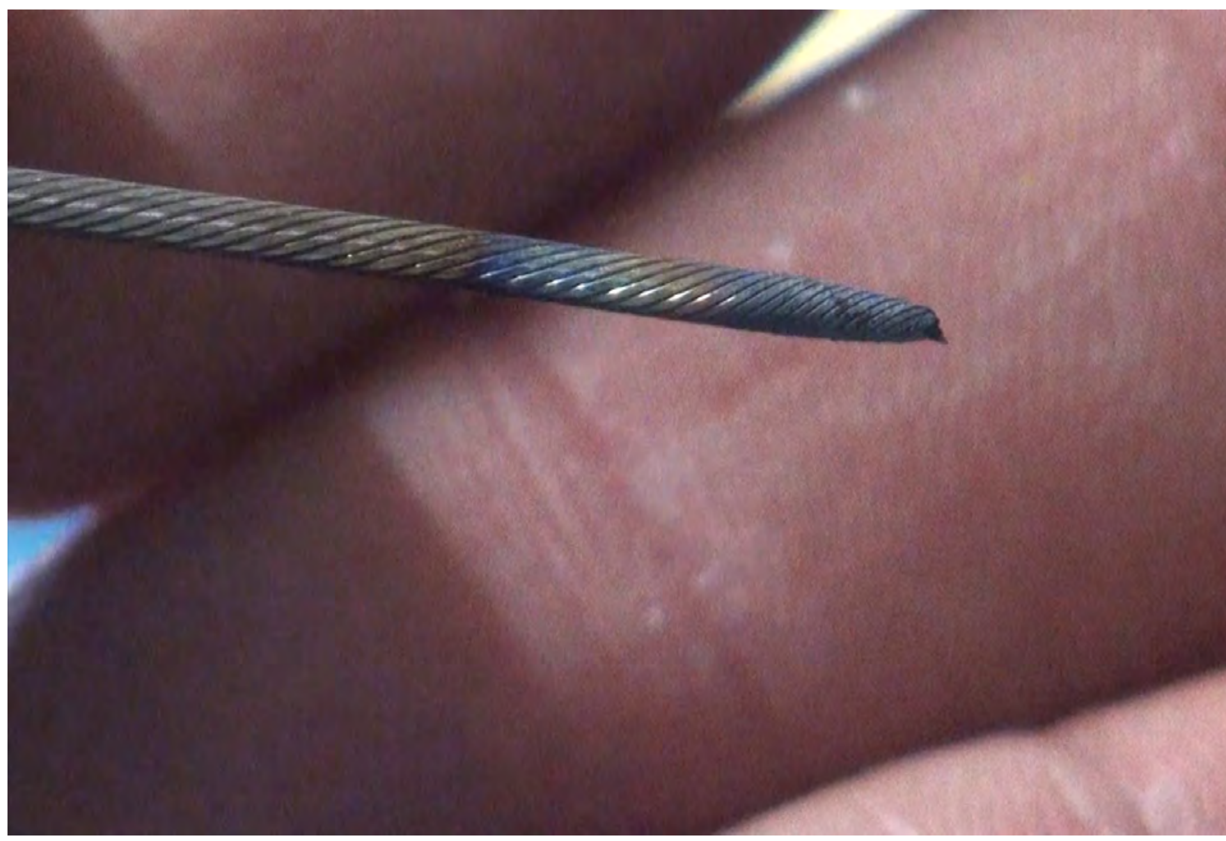

Figure: 1 *“Twist Weld” Cable End Treatment*

We have been using the twist welding method on everything from aircraft control cables to bicycle shifters. One universal problem with any cable is what to do with the that’s been cut off. Many times the cable is in an environment where it is either being manipulated or removed and reinstalled on a regular basis for maintenance purposes. This generally results in the individual wires, within the end of the cable, becoming untwisted and frayed. (*Figure: 2*) This frayed cable end presents a problem. If you pull the cable through the hole, it may not be possible to gather up all individual wires tight enough to actually reinsert them once again (*Figure: 3*).

Figure: 2 *Classic frayed cable end*

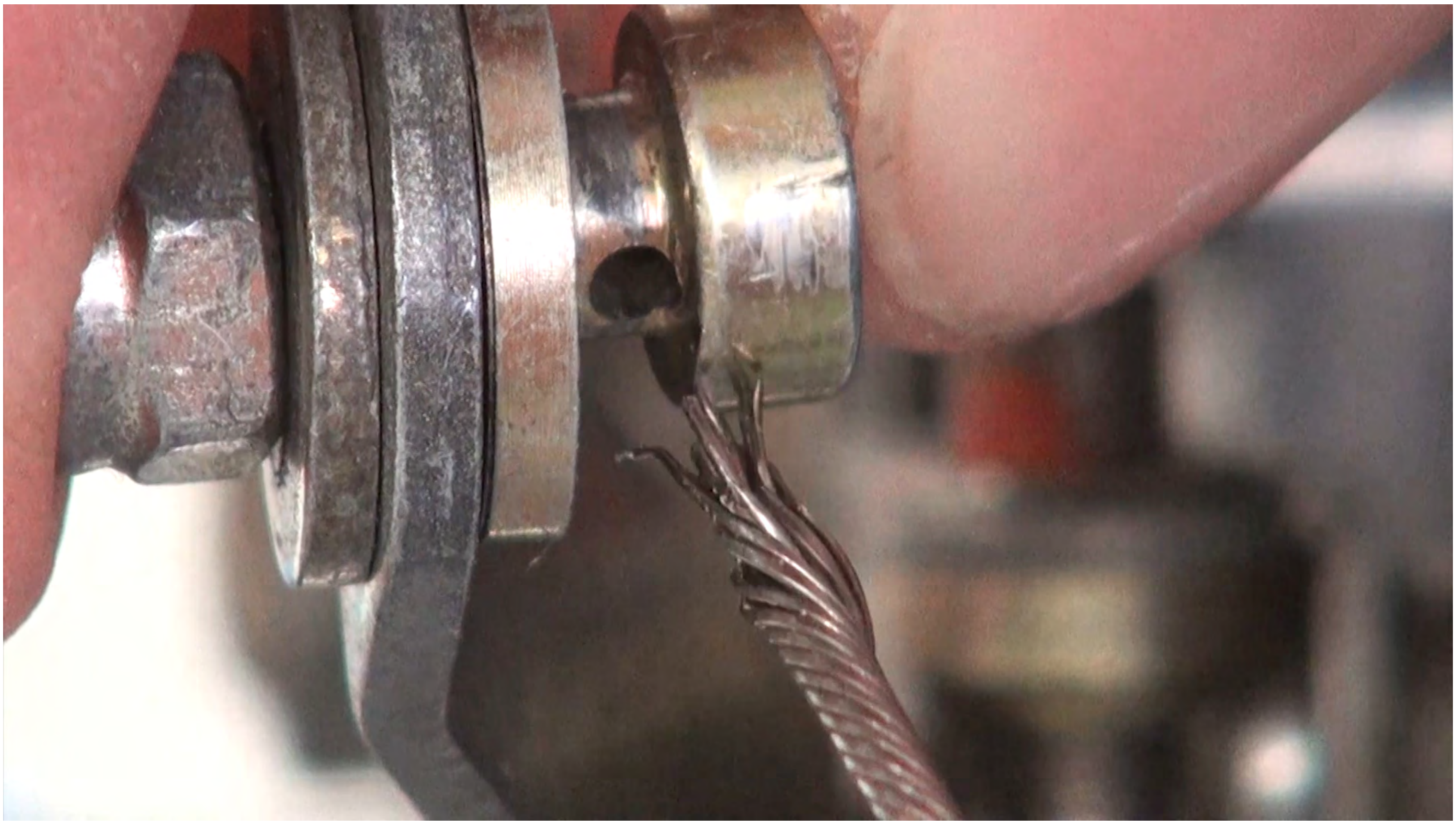

Figure: 3 The impossible task of reinserting a frayed cable end.

One method for handling this is to "Twist Weld" the end of the cable to prevent it from becoming frayed in the first place. This twist weld method is extremely effective and we have yet to see cable treated in this manner become untwisted.

How To

This process is very simple and can be done with hand tools normally found in most toolboxes. All that is required is a slow turning variable speed cordless drill, a propane torch and a vice or a pair of pliers (*Figure: 4*).

Insert the damaged end of the cable into the cordless drill chuck and tighten the chuck on to the cable. Hold the other end of the cable 2 to 4 inches away from the drill chuck using either a

Figure: 4 Only simple hand tools required

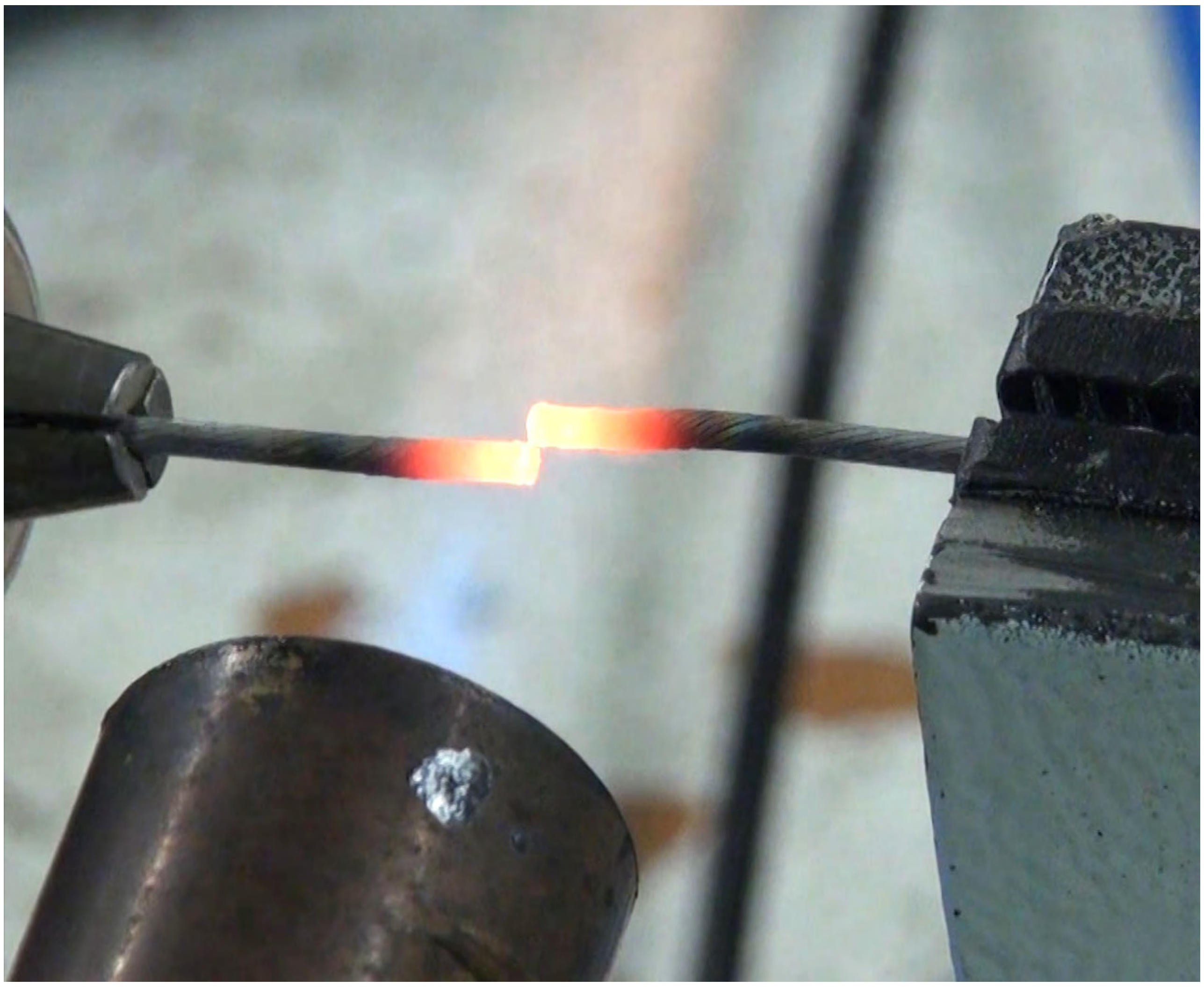

Figure: 5 *Twisting to the point of separation*

vice or a pair of pliers. With a propane torch, on low heat, apply the flame to the cable. Once the cable begins to turn to an orange color, it is time to start spinning the cable at a very low speed. Continue to twist the cable while simultaneously heating. As the cable is twisted, it will fuse the cable wires together forming a solid single wire. Continue twisting until there's enough stress built up in the cable to separate the cable in the 2 pieces (*Figure: 5*).

Refining the Process

A couple of points that will really improve the outcome of this process.

1. Use a cordless drill that turns at a very low speed. Say, somewhere in the neighborhood of 20 to 100 RPM.
2. Apply few pounds of tension on to the cable by pulling the cordless drill during

Figure: 6 *Cable narrowing as a result of tension*

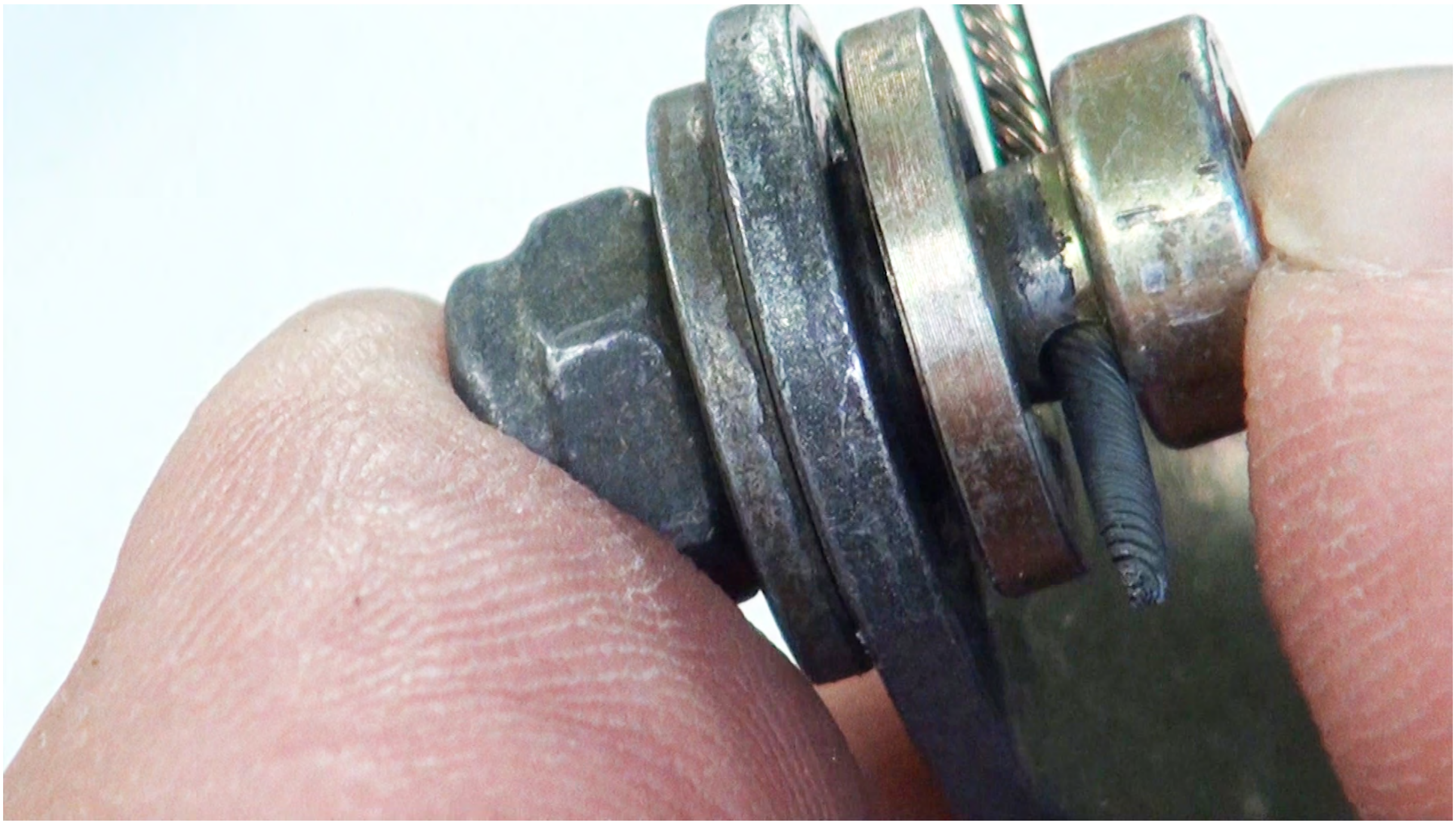

Figure: 7 A narrowed cable end is much easier to insert.

this turning process (*Figure: 6*). This will do two things. First, it will help maintain a nice straight end after the cable separates. Secondly, it helps to narrow the diameter of the cable during the twisting process. This narrowing will make it much simpler to insert into a hole such as the throttle arm on a Bing carburetor (*Figure: 7*).

If we take the cable end, where we have applied the twist weld method, we can sand down the cross-section and reveal the fused nature of each individual wire. The cable wire strands are literally welded together (*Figure: 8*).

Figure: 8 Fused nature of the wires in the cable after twist welding.

Points of Interest

Keep in mind that this process is affecting the structural integrity of the cable, but only in the area where we have applied that heat to the cable. This simply means that you should leave enough additional cable beyond the twist weld area for the actual attachment.

Another factor to take into

consideration, beyond the structural integrity, is the increased susceptibility to corrosion. An example of this is where we have burned off the galvanizing on a steel cable. This will make the cable more susceptible to corrosion.

"The cable wire strands are literally welded together"

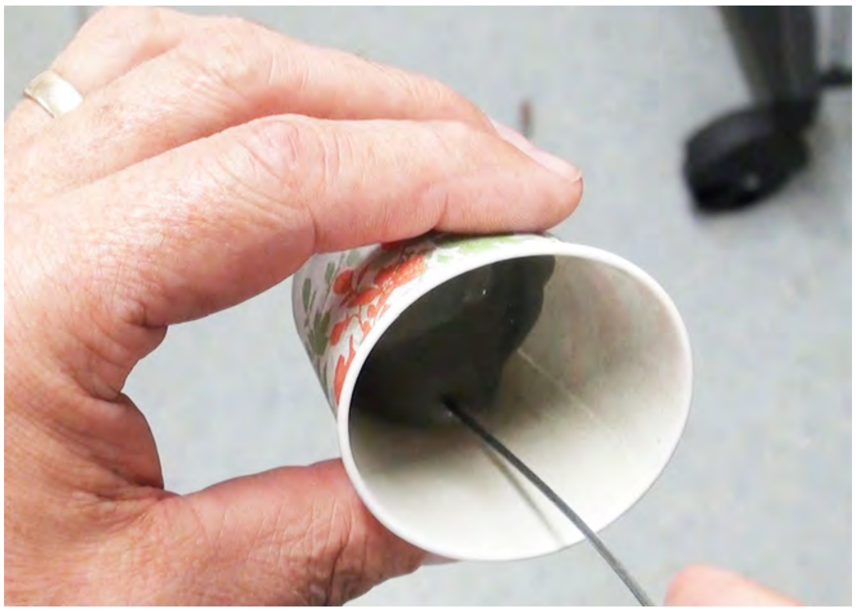

Figure: 9 Dipping the cable in primer for corrosion protection

One way to deal with the potential corrosion problem is to simply dip the twist welded end of the cable into a container of paint or primer. An etching primer from a spray can is thin enough that it will soak into the cable strands when the cable is dipped into the primer.

Spray a small amount of primer into a paper cup, insert the cable, and let it soak for a for a while (*Figure: 9*). Allow the cable can absorb as much of the paint is possible. Remove the cable from the primer and hang it vertically, allowing the excess primer to drip off the end of the cable. This will keep the thickness of the paint on the cable end thin enough that it won't increase the cable diameter and interfere with the ability to insert the cable into a small diameter hole (*Figure: 10*).

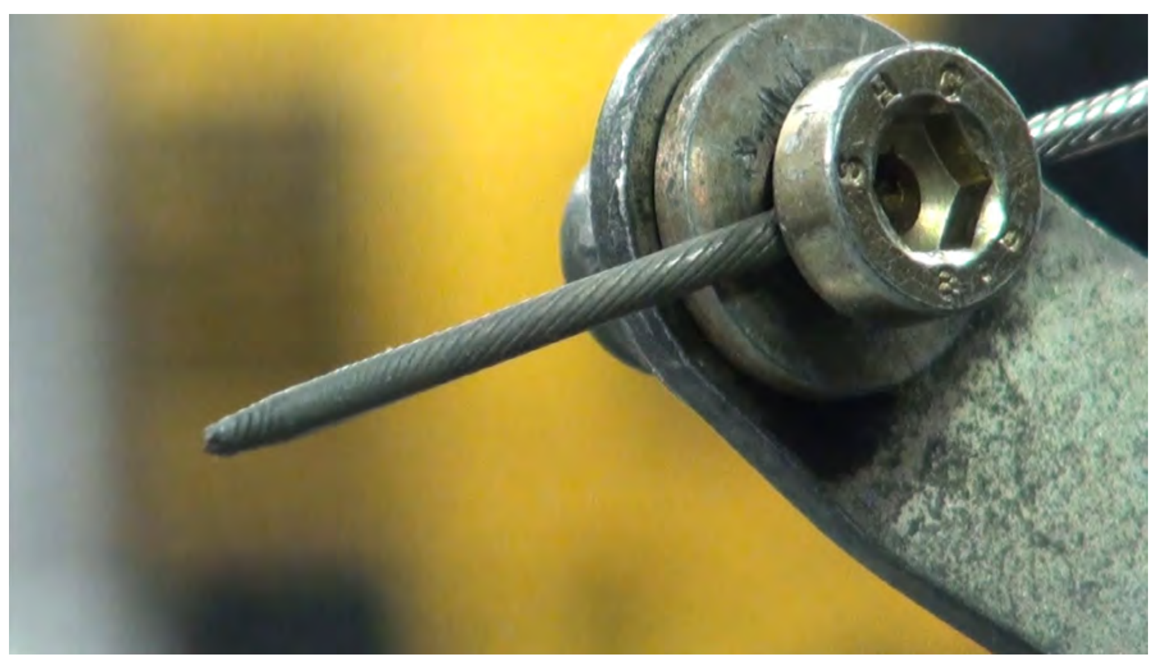

Figure: 10 Twist Weld cable installed

Once you have used the twist weld method you will become a convert. This method works so well, looks so good, and is so quick and easy to accomplish, you will find yourself looking for opportunities to use it on your own aircraft. And it is one trick you'll enjoy sharing with your friends.

[Click Here for Link to YouTube Video on Twist Welding]

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Vinyl Graphics

Carol's Varga Kachina is a great example of vinyl graphics in action. But it wasn't that long ago, that the standard method for applying graphics to an aircraft involved countless hours of laying out the graphic design by using fine line masking tape, masking off the entire aircraft, and then painting a specific color in the graphic. Then, after waiting a few days for the paint to cure, mask off, and repeat the process for each additional color. This tedious, time-consuming, and expensive process relegated most aircraft owners to opt for a simple two-tone color scheme. In addition, the use of straight lines and pin striping were the norm, as this process could be accomplished by the average painter. The use of "swoopy" lines within an aircraft design were normally reserved for only the most elaborate of paint jobs. Creating a "mathematically correct" geometrically curved shape on an irregular canvas, such as an aircraft, using only a roll of fine line tape and a steady hand, required years of experience and a talent only found in a true artist.

This all changed when we finally had the ability to create computer-generated graphics, and then send them off to the sign shop to create even the most complex and visually stunning graphics in a vinyl format. For an aircraft manufacturer, the cost savings in labor to apply vinyl graphics versus the mask and paint method easily won the day. For the aircraft builder vinyl graphics has been catching on a bit slower. The cost of having graphics generated by a sign shop can still be somewhat expensive. The reason relates to the cost of many of these professional vinyl cutting machines which can run $10,000 - $20,000. In addition, the labor for weeding and prepping the vinyl graphics into a "ready-to-install" format for the customer adds to a final cost that makes the average aircraft builder opt for the more labor-intensive, less costly, mask and paint method.

However, in the last 10 years there has been a quantum jump in the number of manufacturers of low-cost vinyl graphics cutting machines. Entry-level machines which are more than adequate for placards and basic graphics on an aircraft costing as little as $200, and professional grade machines capable of creating graphics the entire length of your aircraft, for less than $1000. We have now reached a tipping point where the cost of the vinyl cutting machines can pay for themselves in a single aircraft build. Think of all the placards alone required for a single aircraft: “N” numbers, “Experimental” placards, fuel, oil, coolant, brake fluid, no step, no push, and the list goes on. For the experimental aircraft builder this method of creating placards and graphics on the aircraft has slowly been taking hold as the new normal.

Figure: 1 Roland GS-24 Vinyl Cutter

The vinyl cutter is, for all practical purposes, a three axis CNC machine. At first exposure, you might think that the learning curve for using a vinyl cutter would be substantial. Nothing could be further from the truth. Installing and setting up a vinyl cutter is the equivalent of setting up and installing a personal printer. Our Roland GS-24 vinyl cutter sits adjacent to, and plugs into the USB port, next to our inkjet printer in the Hangar 7 office. (Figure 1) Most of the vinyl cutter manufacturers supply software which is very user-friendly and intuitive. And although not necessary, importing graphics from other software such as Photoshop is a breeze. Once you have set up the vinyl cutter and used it on a regular basis, you will find that cutting a graphic on the vinyl cutter takes about the same amount of time as printing that same sign with an inkjet printer onto a piece of paper.

Let’s step through the workflow process to give you an idea of how we take a concept on paper all the way to a finished product installed on the aircraft. First, we lay out our design in the software. Once we are satisfied with the design, we simply tell the machine to process the cut. The vinyl material comes attached to a backing material. The knife blade of the vinyl cutter cuts just through the top layer of vinyl without cutting through the backing material. We will next bring the cut vinyl to a clean bench to begin the process of “weeding”. (figure 2) Since the vinyl cutter has cut a razor thin line around each one of our letters, we simply remove all the unwanted material around the perimeter and from the interior of any closed letters using a variety of weeding tools like tweezers and picks. The backing material has a nonstick waxy feeling surface which allows the vinyl to easily be removed. On occasion you may find one of your letters trying to peel up as you remove the excess vinyl material. This requires that you proceed slowly and deliberately to ensure that you are getting only the excess material removed. This process takes only a few minutes on items like this “experimental” placard. However, on small and very intricate designs the process can be a bit more tedious. Once we have removed the excess vinyl, we are left with

Figure: 2 Vinyl Graphic “Weeding”

the design or letters that will be installed on the aircraft. The next step is to apply a transfer tape over the top of the vinyl graphic and backing material. Transfer tape is applied from one edge peeling back the protective backing layer as you squeegee the transfer tape onto the vinyl letters. (figure3) the transfer tape has more sticking power than the vinyl letters have to the “waxy” backing material. This is what allows us to peel away the backing material and have the letters stuck to the transfer tape. However, the stickiness on the vinyl letters, once adhered to a clean surface, have more sticking power than the adhesive on the transfer tape. It’s a rather ingenious system.

Once you have the transfer tape installed, you now have a sandwich of material. The top layer of transfer tape, the middle layer with the vinyl graphic, and the bottom layer with the backing material. This allows us to keep the vinyl protected from dust and contamination during the storage and installation process. Once we are ready to install the graphic, we prep the surface by cleaning it thoroughly. Even the slightest

Figure: 3 Applying Transfer Tape

Figure: 4 Applying the Vinyl Graphic

bit of dust will be evident in the final product. By leaving the backing material in place we can position the graphic onto the surface holding it in place with tape while we take measurements to ensure that it is correctly positioned. We like to split the graphic down the middle and remove only half of the backing material, working from the center of the graphic and using a squeegee to lay the material down a bit at a time ensuring that no wrinkles or air bubbles get into the vinyl graphic. (figure 4) once the first half has been laid down permanently, the opposite side can now be laid down in the same fashion using a squeegee working from the center out to the opposite side of the graphic. On simple single-color graphics, like the Rainbow Aviation logo, we normally install them dry. This is a bit of a double edge sword. The second that the vinyl contacts the surface it is STUCK. This requires precision positioning before you begin removing the backing material and careful handling during the installation to avoid inadvertent contact with the surface. The upside is, the installation is a bit quicker and generally a cleaner installation without any air bubbles or wrinkles if done correctly.

Figure: 5 Multi-layered Vinyl Graphics

For more complex multilayer/multicolor graphics on a compound surface we typically opt for using the wet method. This involves using a mild soap solution sprayed onto the application surface prior to applying the graphic. This will allow us to slide the graphic on the surface until it is perfectly positioned in relationship to all the other previously installed graphic segments. (figure 5) Creating graphics much larger than your vinyl cutter capacity is possible by segmenting your graphics into smaller sections and then piecing them together. We will normally splice the graphics where there is a natural seam or joint in the structure. For example, we will cut the section of a graphic out for a door. Leaving extra material extending past the edges of the door allowing us to be able to wrap the vinyl graphic around the edge of the door and doorjamb. This provides for a much cleaner and more professional looking installation. In addition, by breaking the overall graphic up into smaller pieces it becomes much easier to manage on a large canvas such as an aircraft fuselage.

Having a vinyl cutter at your disposal really opens a lot of opportunities. If you're thinking about purchasing one and using it on your aircraft, we recommend purchasing it ahead of time so that you can work out the learning curve doing smaller projects first. After using it on a regular basis, you will soon develop that confidence that will allow you to tackle those bigger jobs.