Propeller Bolt Belleville Washer Installation Instructions

Marc J. Zeitlin
23501 Fir Drive
Tehachapi, CA 93561
(978) 502-5251
marc_zeitlin@alum.mit.edu

September 12th, 2017

Revision: R

Table of Contents

1) General Information

1.1) Preamble

1.1.1) Propeller Bolt Torque

Although variability exists in Propeller Bolt Torque Measurements and we would rather be able to directly measure bolt stretch and propeller hub compression, given the variability in hub stiffness and belleville washer manufacturing tolerances we will use prop bolt torque as a sufficient method for ensuring that we apply the correct compression to the hub and tension on the bolts.

1.1.2) Torque Variation Example

When I first installed the bolts with four Belleville washers, I got an average torque measurement of 29 ft-lb at 4 bolt turns. The next time, I got an average torque measurement of 60 ft-lb, at four turns - exactly the same washer compression (0.043 in./washer, within a couple of thousandths of an inch). Other users have also obtained anomalous torque numbers in a few trials. There sometimes exists a tenuous relationship between torque and washer compressive force – measured torque is dependent on many factors, such as cleanliness of threads, temperature, humidity, tightness of bolt in prop hub through holes, etc. Proper preparation of the propeller bolts becomes critical to correct installation.

1.1.3) Over-Tightening

It is possible to over-tighten bolts and crush the prop hub wood fibers. We'd like to always have at least 600 psi but no more than 900-1000 psi on the hub (depending upon the wood type – see the calculation spreadsheet for the exact numbers for your prop material). Excess pressure not only can harm the wood but also takes away from the ability of the washers to accommodate wood growth with moisture absorption. Tighter is **NOT** always better.

1.1.4) Appropriate Tightness Levels

The correct "tightness" for the bolts (as determined by the Belleville Washer compression measurements) is set by the Propeller Manufacturer's torque specification and backed up by the calculation spreadsheet, filled out with **YOUR** appropriate installation information. The bolt torque may vary substantially with bolt tightening - it may vary from somewhat below the prop manufacturer's recommendation (if the bolt threads are clean and there's little friction between the washers during tightening) to more than twice that (if the converse is true, and the holes are tight due to cold/dry conditions).

While we will use torque as the main determinant of proper bolt "tightness" or washer compression, we may use washer compression as a backup.

1.1.5) Hub Compression

The compression of the prop hub, while theoretically 0.006 in./in. of thickness (for Hard Maple – other woods will have different compression values) can vary substantially (sort of like the torque). I believe that this is dependent upon how long the prop has had compressive force on it, as well as how long you let it relax after loosening the bolts, as

well as the wood specie. It can take days or weeks for the wood to fully compress or relax. I believe that wood has some hysteresis effect, as well as being far more variable as far as stiffness goes than any metal.

1.1.6) Appropriate Monitoring

The **main** thing that we need to monitor on an ongoing basis is the prop bolt torque, with compression of the Belleville Washers as a backup.

The Belleville Washer Compression is the number that sets the force on the crush plate/propeller hub and that force is what gives the driving friction - everything else - bolt torque, hub compression measurement, bolt stretch, even bolt turns - is just an **indirect** method of measuring the force on the hub, with varying accuracies.

1.2) General Bolt Length Determination

The propeller bolts must be long enough to ensure adequate thread engagement in the lugs (or nuts, if threaded lugs are not used) so that full thread strength without stripping is achieved. This will generally be approximately one bolt diameter of engagement – i.e, for ½-20 bolts, about ten full threads. For 3/8-24 bolts, it would be about nine full threads of engagement.

The propeller bolts must also have a short enough shank (unthreaded) length so that they do not bottom out in the lug (or nut) prior to attaining full compression on the belleville washers.

These two conditions bound the requirements for bolt shank and overall length. The proper bolt length can only be determined for a given prop, crush plate belleville washer and flat washer stack and prop flange installation by knowing all those dimensions and calculating the maximum bolt shank length and minimum bolt overall length, or by trial and error.

This is no different than **ANY** propeller bolt installation – in no case can the prop bolts be allowed to bottom out on the threads, and they all must have enough thread engagement. In our case, with belleville washers, we just need to add the belleville/flat washer stack height to the overall length of the bolt.

Everyone **MUST** verify these measurements on **THEIR** installation. This should first be verified with **NO** Belleville washers installed. Measure the distance between the two large area washers when the bolt **IS** bottomed out on the threads, and ensure that you cannot get four belleville washers into the space between the two large area washers (AN-970) even if the bellevilles were flattened (i.e., using the material thickness of the belleville as the gauge thickness..

If you **CAN** bottom the bolt, you can add extra AN-960 washers under the bolt head to take up the necessary space.

Ensure that you have proper thread engagement **WITH** the bellevilles installed and finger tight, as well as when tightened to the correct torque and Belleville washer compression target.

2) Bolt Installation Instructions

This section includes instructions for four bolt sizes.

2.1) Assumptions:

There are many different combinations of Propellers, Flanges, Crush Plates, Prop Hub Thicknesses, Prop Materials, and Bolts. In order to use this configuration of Belleville Washers, the following assumptions were made. If you have **ANY** questions regarding whether or not your configuration is appropriate for this installation, **ASK FIRST**.

2.1.1) Prop Mounting Flange Diameter / Specification

2.1.1.1) ½" Bolt Flange Information

The expectation for ½" bolts is that you will be using an SAE-6 flange with a 6" or 7" diameter face.

2.1.1.2) 7/16" Bolt Flange Information

The expectation for 7/16" bolts is that you will be using an SAE-4 or SAE-5 flange with a 6" or 7" diameter face. If this is not the case for your propeller, please contact me for guidance prior to installation.

2.1.1.3) 3/8" Bolt Flange Information

The expectation for 3/8" bolts is that you will be using an SAE-1, 2 or 3 flange with a 5.5" – 6.5" diameter. If this is not the case for your propeller, please contact me for guidance prior to installation.

2.1.1.4) 5/16" or 8 mm Bolt Flange Information

The expectation for 5/16" bolts is that you will be using a flange with a 4" – 5" diameter face. If this is not the case for your propeller, please contact me for guidance prior to installation.

2.1.2) Prop Crush Plate Diameter / Specification

The propeller crush plate diameter is usually the same diameter as the propeller mounting flange size, to ensure the same compressive loads on both sides of the propeller hub. If they are **NOT** the same, however, the spreadsheet will take that into account and use the smaller of the two to calculate the drive face area.

2.1.3) Prop Hub Thickness

2.1.3.1) ½" Bolt Hub Thickness

In general, ½" bolt, SAE-6 flange propellers will have hub thicknesses in the 4" – 5" range, but this will be dependent upon the pitch of the propeller. If your hub is not in this thickness range, please contact me for guidance prior to installation.

2.1.3.2) 7/16" Bolt Hub Thickness

In general, 7/16" bolt, SAE-4 or 5 flange propellers will have hub thicknesses in the 3.75" – 5" range, but this will be dependent upon the pitch of the propeller. If your hub is not in this thickness range, please contact me for guidance prior to installation.

2.1.3.3) 3/8" Bolt Hub Thickness

In general, 3/8" bolt, SAE-1, 2 or 3 flange propellers will have hub thicknesses in the 3.75" – 5" range, but this will be dependent upon the pitch of the propeller. If your hub is not in this thickness range, please contact me for guidance prior to installation.

2.1.3.4) 5/16" or 8 mm Bolt Hub Thickness

In general, 5/16" bolt propellers will have hub thicknesses in the 2" – 4" range, but this will be dependent upon the pitch of the propeller. If your hub is not in this thickness range, please contact me for guidance prior to installation.

2.1.4) Prop Material

We assume that the core of the propeller, whether or not it has a composite overwrap as do the Hertzler and Catto props, is a hardwood such as Maple. A pull-down list allows you to set the wood specie for **YOUR** propeller in the spreadsheet. If your wood specie is not listed as a choice, please contact me for guidance prior to installation.

2.1.5) Bolt Count

Although there may be some propeller hubs somewhere that have bolt counts that aren't "six", I've never seen any. If you somehow have a configuration that doesn't have six prop bolts, contact me for guidance prior to installation.

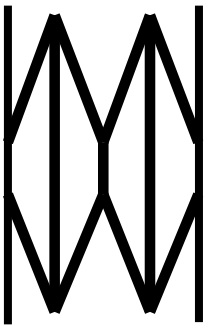
2.2) General Overview:

2.2.1) ½", 3/8" and 5/16" or 8 mm Bolt Washer Arrangement

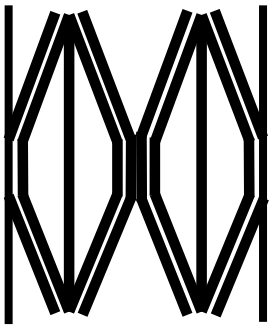
For each bolt, the bellevilles will almost certainly be arranged in two opposition pairs, with the **SMALL** end against the two wide area washers. Like this:

AN-970 wide area washer, four bellevilles, AN-970 wide area washer in sequence with the bellevilles opposing one another.

Some folks use two washers rather than four in certain cases – that can also be acceptable and the spreadsheet will calculate the correct values.



2.2.2) 7/16” Bolt Washer Arrangement

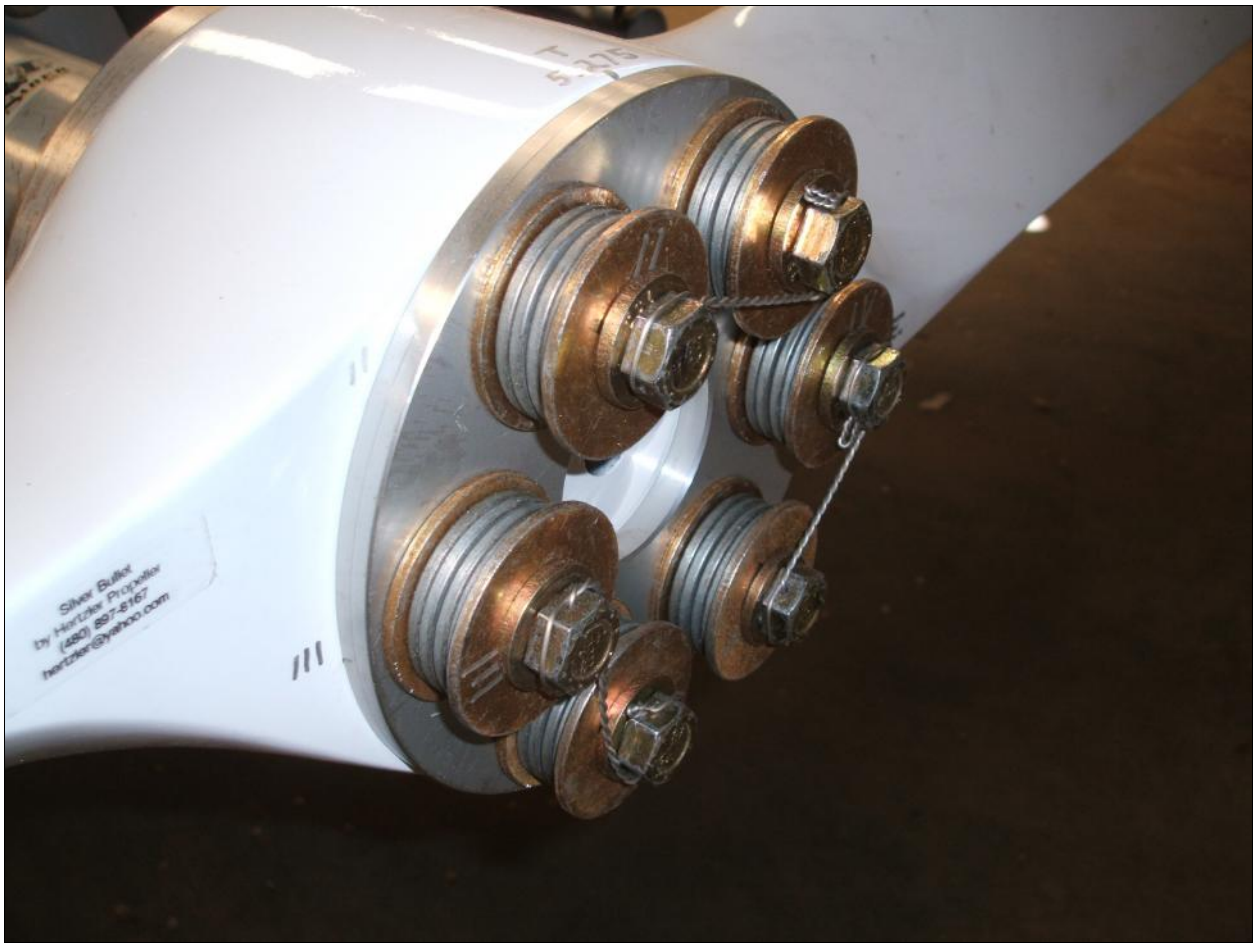


For each bolt, the bellevilles are arranged either as described above, or possibly in two opposition sets for a total of eight bellevilles, with the **SMALL** end against the two wide area washers. Like this:

AN-970 wide area washer, eight bellevilles, AN-970 wide area washer in sequence with the bellevilles opposing one another in nested pairs.

Which of the two arrangement types you will use for the 7/16” bolts will be determined by the results of the spreadsheet calculator.

This is approximately what your installation will eventually look like:



2.3) Installation Steps:

2.3.1) Arrange Components

Arrange all the parts (hard washer [if necessary for spacing and available - if not, use a standard AN-960 washer], AN-970 large area washer, bellevilles as indicated in the correct order as shown above, AN-970 large washer) onto each of the six bolts.

2.3.2) Thread Preparation

Ensure the bolt threads and lug threads are clean and lubricate the lug threads with light oil or per the propeller manufacturer's instructions for installation.

2.3.3) Prop Extension Positioning

Position the propeller extension/engine at engine cylinder #1 TDC for future reference. Install the prop per the prop manufacturer's instructions on prop extension, ensuring that the prop is flush against the extension.

2.3.4) Using the "Belleville Washer Analysis Calculator" Spreadsheet:

2.3.4.1) Introduction

With this document you have downloaded a spreadsheet to use to calculate the "**Total Belleville Washer Compression Target Measurement"** for **YOUR** specific installation configuration. The instructions for using the spreadsheet are in the spreadsheet, right next to the calculations.

2.3.4.2) Input All Configuration Information

There are fourteen configuration input parameters for a given propeller installation, that involve the bolt, the prop hub, the prop drive flange plate and the belleville washer arrangement, as shown in the previous section(s).

Use the instructions on the spreadsheet to input these parameters and ensure that they are correct for **YOUR** installation.

2.3.4.3) Obtain "Total Belleville Washer Compression Target Measurement" Output

Once all fourteen input parameters are correct, follow step 14 in the spreadsheet calculator. This will give you your **"Total Belleville Washer Compression Target Measurement"** as an output, while ensuring that you're compressing the Belleville washers enough (but not too much) and not crushing the wooden prop hub.

The **"Estimated Bolt Turns"** is also shown as an output of the spreadsheet. This is, in a perfect world, how many turns of each propeller bolt you would need to achieve the necessary washer compression. But due to variations in wood stiffness, preload, etc., you may need more (or rarely, fewer) turns to get the necessary compression.

In any case, we will use the Propeller Manufacturer's recommended bolt torque specification for tightening the prop bolts, and will use the "Compression Target" and "Estimated Bolt Turns" as backup confirmations **ONLY**.

2.3.5) Bolt Insertion / Tightening

Insert bolts into prop and tighten each bolt to ¾ of the **"Estimated Bolt Turns"** or ¾ of the MFG's recommended torque with a wrench to get the propeller seated against the extension – ensure that the propeller cannot move away from the flange.

Some users have found that the prop hub will "relax" overnight, possibly due to not pre-tightening adequately, or due to hub settling. You may want to allow the prop to sit for a few hours (or overnight) prior to loosening the bolts to ensure the wood is compressed adequately.

Then loosen the bolts until the AN-970 washers are again just **BARELY** loose. Do **NOT** pull the propeller off of the extension, or otherwise move the propeller.

At this point, tighten the bolts using the Propeller MFG's recommended bolt torque specification and a calibrated torque wrench. Tighten to ½, ¾ and full torque while tightening in a pattern to avoid tightening two neighboring bolts in sequence.

With finger tight bolts, using a standard tightening pattern (1, 4, 2, 5, 3, 6), tighten each bolt approximately one third of the **"Estimated Bolt Turns"** determined in the previous section, using a long handle wrench. Use a **"Beam Type"** torque wrench if available – it's far easier to determine intermediate torque levels. A "Clicker Type" torque wrench can be used if that's all that's available. But do **not yet** use the torque values to determine when to stop tightening the bolt.

Repeat so that each bolt is turned approximately 2/3 of the total number of turns as shown in the spreadsheet, and then to the full MFG's torque specification, using the following bolt tightening pattern for the second and third pass through the bolt tightening sequence:

Pass 2: 6, 3, 5, 2, 4, 1

Pass 3: 3, 6, 5, 2, 1, 4

2.3.6) Bolt Tightening – Caution:

Always ensure that you tighten every bolt to the Manufacturer's Bolt Torque specification level.

Having either too high a torque level (or too high a washer compression or exceeding the wood compressive stress margin) may put excessive compressive stress on the prop hub, may crush the wood fibers and may give inadequate relief space in the belleville washer stack to allow for prop hub expansion.

Having too **LITTLE** compression on the wood or the washers may lead to prop slippage, bolt breakage, and a need for a glider rating.

3) Common Installation Steps

3.1) Prop Tip Tracking

At this point in the procedure, track your prop tips per your normal procedure. If you need to adjust the propeller tip position, you may tighten the two or three bolts nearest one tip or loosen the two or three bolts nearest the other tip. Tightening bolts is preferable to loosening:

3.1.1) ½" Bolts

BY NO MORE THAN 1/4 BOLT TURN (One and one half "flats") IN EITHER DIRECTION

3.1.2) 7/16", 3/8" or 5/16" or 8mm Bolts

BY NO MORE THAN 1/6 BOLT TURN (One "flat") IN EITHER DIRECTION

3.2) Safety Wire Bolt Heads

Safety wire all bolts in pairs – I do not recommend using a single safety wire for all six bolts, or for any more than two. Ensure that you do an excellent job of safety wiring, and that the wires are tight.

3.3) Test Sighting of Bellevilles

Note that if you sight down vertically between the bellevilles, you will be able to see a tiny bit of light between the convex surfaces of the bellevilles - they must **NOT** be bottomed out or touching along the whole face.

3.4) Go Fly

You should **NOT** notice a difference – as far as the prop, bolts and engine are concerned there is no difference from the standard methodology of installation. All you're doing is giving yourself safety margin in the case that the prop hub grows or shrinks. However, if there's **ANY** vibration that's different than normal, land immediately and check everything.

3.5) Post Flight Measurements

After the first 10 hours of flight or engine running, remove the safety wire from the prop bolts and dynamically measure the torque on each bolt (back off the bolt by ¼ turn, then re-tighten to the correct torque). Do the same after 25 hours post installation. From that point on, a torque check will only be necessary at each yearly condition inspection to look for any changes.

4) Conclusions:

4.1) ½ in. Bolts:

With a nominal 30 ft.lb., **THREE** turns on each bolt, the compression of each Belleville stack (the difference between the stack height at "finger tight" and at **THREE** turns) should be approximately **0.130 in.** It could be **0.005 in. to 0.010 in.** off of that on either side to start - what's important is not the exact measurement, but how even it is between bolts and how much it changes with time.

If **YOUR** installation configuration or prop MFG specification leads to different numbers than those shown above, that's OK – use **YOUR "Torque",** "**Turns**" and "**Compression**" numbers as references for future measurements.

Over time, we shouldn't ever see the compression distance change by more than **0.005 in. to 0.010 in.** or so, I don't believe, if we don't touch the bolts. Even 0.020 in. of change, from 0.110 in. to 0.090 in. of compression, would only lower the compressive force on the crush plate by approximately 15%. This should **NOT** be an issue, and is a far higher change in hub thickness than I can imagine occurring.

4.2) 7/16", 3/8" and 5/16" or 8 mm Bolts:

The same logic applies as for the ½" bolts – only the starting "Torque", "Turns" and "Compression" numbers will be different.

If **YOUR** installation configuration leads to different numbers than those shown above, that's OK – use **YOUR "Torque", "Turns**" and "**Compression**" numbers as references for future measurements.

4.3) Questions / Feedback:

Any questions or feedback on the procedures or theory espoused here is **MORE** than welcome.

5) Appendix A: Belleville Washer MFG Data

Manufacturer: **Solon MFG**
425 Center Street
P.O. Box 207
Chardon, Ohio 44024-0207
Phone (800) 323-9717
(440) 286-7149
Fax (440) 286-9047

Ordering Info: Solon MFG is the manufacturer of these washer, not a distributor. They may only want to sell direct to companies (not individuals), but they DO take credit cards for phone orders. If you give them a business name for shipping purposes, you should be able to order them directly. If not, you may need to find a distributor. Apparently Fastenal is a distributor of some Solon part numbers.

Bolt Size	Part Number	O.D.	Material	Max. Deflection	Thickness	Max. Load
½ inch	828131	1.75”	6150 Steel	0.051”	0.134”	7,000 lb.
7/16 inch	7H89	1.188”	6150 Steel	0.025”	0.091”	3800 lb.
3/8 inch	620125177	1.25”	17-7PH SS	0.022”	0.125”	5,000 lb.
5/16 inch	5EH80	1.063”	6150 Steel	0.032”	0.083”	2800 lb.
5/16 inch	5EH80177	1.063”	17-7PH SS	0.023”	0.083”	2300 lb.
8 mm	5EH80	1.063”	6150 Steel	0.032”	0.083”	2800 lb.
8 mm	5EH80177	1.063”	17-7PH SS	0.023”	0.083”	2300 lb.

6) Appendix B: Revision History

Revision	Description	Date
Draft	Original write-up – adaptation for ½" and 3/8" bolts	9/2008
A	1. Add Title Page 2. Add TOC 3. Add 7/16" Bolt size 4. Rearrange per bolt size 5. General reformatting – ready for release 6. Remove "**Draft**" Watermark	2/6/2009
B	1. Adjust **ALL** sections for latest compression calculations	2/21/2009
C	1. Fix 7/16" Washer arrangement text and pictures – sections **2.2.2** and **4.3** 2. Minor wording issues in other sections	2/27/2009
D	1. Changed 7/16" washer part number from 7H89301 to 7H89 2. Condensed sections 2, 3, 4 3. Included references to Washer calculator spreadsheet to determine number of turns	4/3/2009
E	1. Fix section **4.X** wording of changes in compression	8/30/2011
F	1. Added Solon MFG contact information – Appendix A 2. Added Solon MFG ordering information – Appendix A	9/25/2011
G	1. Added 5/16" bolt washer instructions 2. Revised SAE flange information 3. Rewrote "Over-Tightening" section 4. Removed torque references 5. Added Solon MFG info for 5/16" bolts washers	12/29/2011
H	1. Fix Heading 2 formatting 2. Renamed "Bolt Bottoming" to "General Bolt Length Determination" in section **1.2)** 3. Added additional Bolt Length determination instructions	4/28/2012

Revision	Description	Date
I	1. Update for addition of 8 mm bolts 2. Update for changes to spreadsheet	12/22/2012
J	1. Fix minor typos	12/29/2012
K	1. Update for changes in spreadsheet to emphasize washer compression, not bolt turns 2. Re-arranged spreadsheet usage to earlier in document 3. Added Error! Reference source not found. graphic	9/30/2013
M	1. Prop Extension Positioning – added “cylinder #1” for accuracy 2. Bolt Insertion – change ½ to ¾ of estimated bolt turns; Add paragraph about “relaxation” 3. First Pass – remove reference to “noting # of bolt turns” 4. Bolt Tightening, Continued – fixed “Y” to be “X” in second image; reformatted section for pagination 5. Bolt Tightening sections – added reference to “Measurement” tab in spreadsheet – multiple places 6. Notification – added “if you desire”	11/19/14
N	1. Modified **1.1.1)**, **1.1.2)**, **1.1.4)** and **1.1.6)** to accept torque as backup tool for hub compression 2. Update Error! Reference source not found. and Error! Reference source not found. to reflect usage of torque wrenches and torque measurements **3.** Change safety wire requirement to recommendation in **3.2)**	06/21/15
P	1. Remove 720125177 7/16” washers – don’t exist	8/23/15
R	1. Simplify instructions for torque as primary measurement – remove measurement instructions	9/12/17