Propeller Bolt Belleville Washer Installation Instructions

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

June 21st, 2015

Revision: N

Table of Contents

1) General Information

1.1) Preamble

1.1.1) Propeller Bolt Torque

Propeller Bolt Torque measurements **are not a sufficient methodology for determining prop hub compression.** I can't stress that strongly enough – while measuring bolt torque can be a useful and meaningful backup for tightening the propeller bolts, there is way too much variability in torque application and determination of hub compression to be the sole methodology for bolt tightening unless continual maintenance occurs.

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 is 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.

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 calculation spreadsheet, filled out with **YOUR** appropriate installation information. The bolt torque could vary substantially with bolt tightening - it could vary from approximately the prop manufacturer's recommendation (if the bolt threads are clean and there's little friction between the washers during tightening) or more than twice that (if the converse is true, and the holes are tight due to cold/dry conditions).

Do not solely use torque as a determinant of proper bolt "tightness" or washer compression. Washer compression is used to ensure appropriate prop bolt "tightness" and hub compression pressure, with torque used only 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 compression of the Belleville Washers – measurement **"X"** in section **2.3.8.1),** as well as ensuring that we have at least the minimum torque as specified by the propeller manufacturer.

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 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.

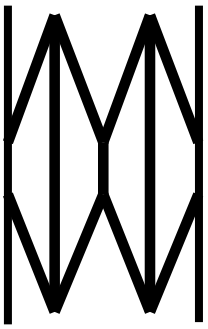
2.2) General Overview:

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

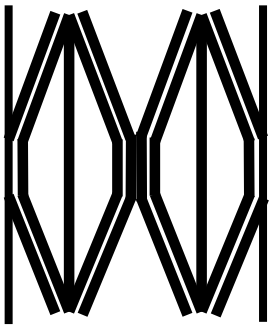
For each bolt, the bellevilles will almost certainly be arranged in two opposition pairs, with the **SMALL** end against the two wide area washers. Like this:

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

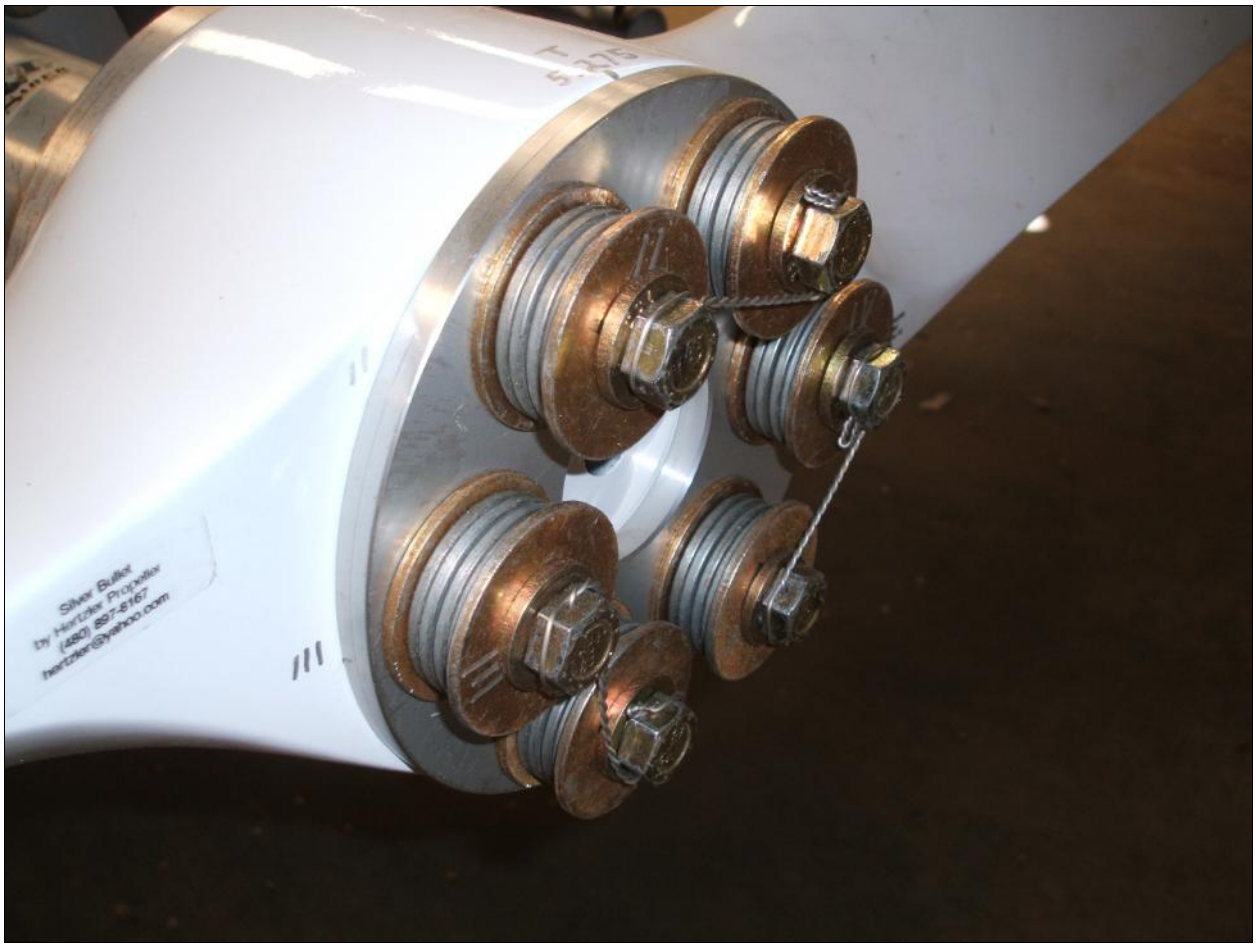


For each bolt, the bellevilles are arranged either as described above, or possibly in two opposition sets for a total of eight bellevilles, with the **SMALL** end against the two wide area washers. Like this:

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 lubricated with beeswax or the functional equivalent, 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.

Note: 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. **USE THE COMPRESSION NUMBER AS YOUR GOAL – the Bolt Turns is just an estimate.**

2.3.5) Bolt Insertion

Insert bolts into prop and tighten each bolt to ¾ of the **"Estimated Bolt Turns"** 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 has "relaxed" 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.

2.3.6) Hand Tighten

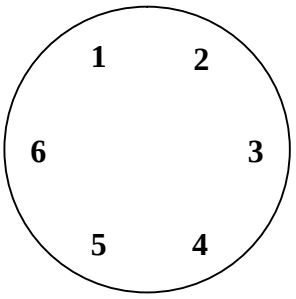
Next, hand tighten (you can use a wrench if required) until all bolts are "finger" tight - you should **JUST** barely be able to turn the outer AN-970 large area washer with your fingers. This is now the starting point for all further tightening of the bolts. The purpose of this is to ensure that all bolts create the same compression on each bolt's set of bellevilles.

2.3.7) Marking Bolts

Using an indelible marker, or a paint pen, mark each bolt so that you know which "flat" on the bolt head is "up".

2.3.8) Marking Sequence

Mark each bolt with a number (1-6) in sequence like so:

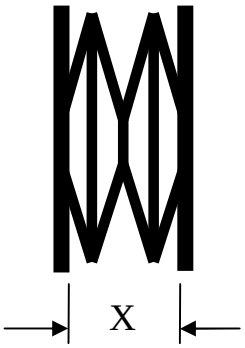


Measurements:

2.3.8.1) Washer Distance

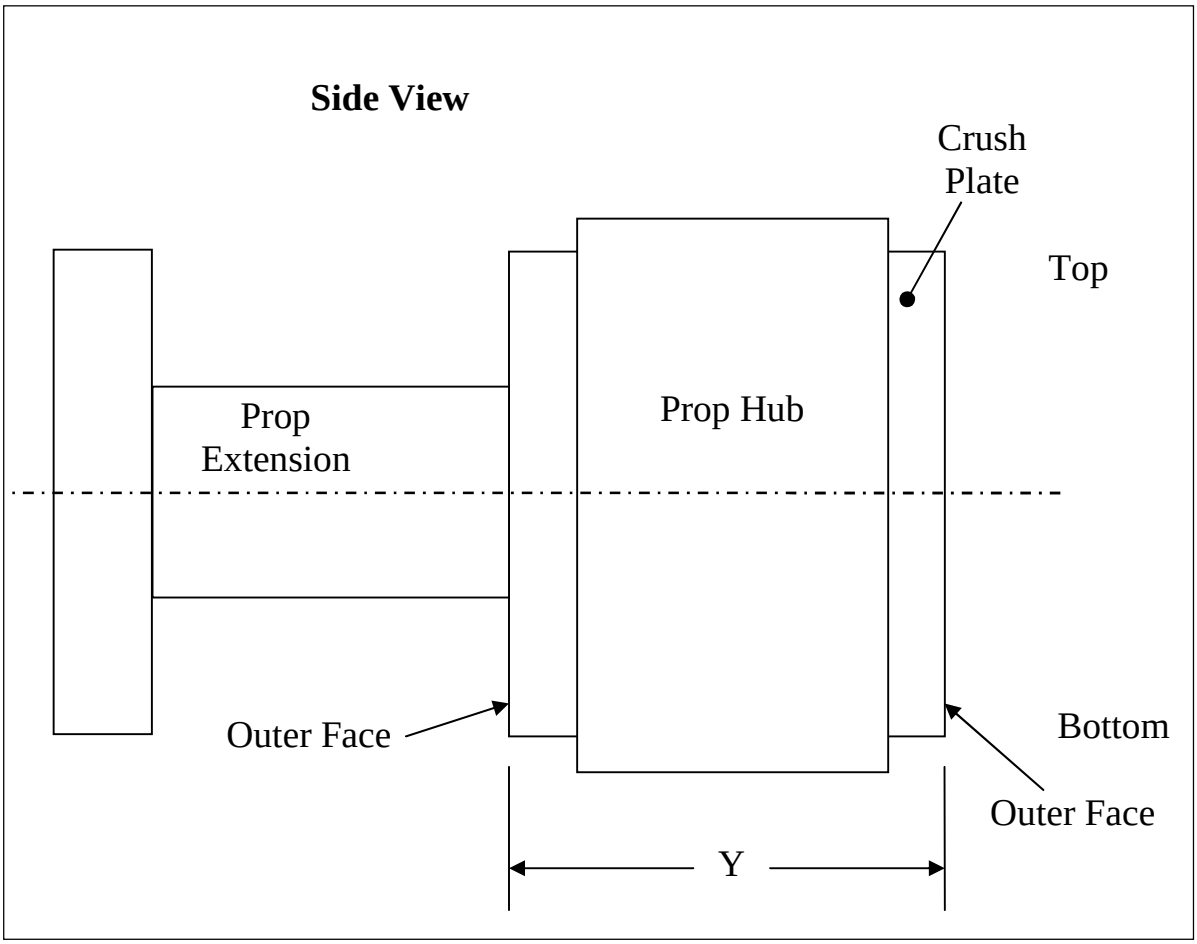
Measure the distance "X" between the inner faces (the faces that touch the belleville washers) of the two large area washers on each bolt with an internal measurement calipers and write it down, noting which bolt has which measurement. Each time you measure, do so in the same place on the washers, for consistency.

THIS IS THE MOST IMPORTANT MEASUREMENT YOU WILL MAKE!



2.3.8.2) Hub Distance

Measure the distance from the outer face of the crush plate to the outer face of the prop extension (the distance that **INCLUDES** the thickness of the propeller hub) at both the top and bottom and write these measurements down. This measurement will help me determine the correlation between the Forest Service stiffness #'s and what we actually get for our propellers, and help make the spreadsheet more accurate over time.



2.3.9) Bolt Tightening:

2.3.9.1) First Pass

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.

2.3.9.2) Washer Measurement

Measure the distance between the two AN-970 large area washers on each bolt (as in section **(2.3.8.1)** and write it down or use the "Measurement Inputs and Results" tab in the spreadsheet to track your measurements.

2.3.9.3) Hub Measurement

Measure the distance from the outer face of the crush plate to the outer face of the prop extension at both the top and bottom (as in section (**2.3.8.2))**. Write these measurements down or use the "Measurement Inputs and Results" tab in the spreadsheet to track your measurements.

2.3.10) Bolt Tightening - Continued:

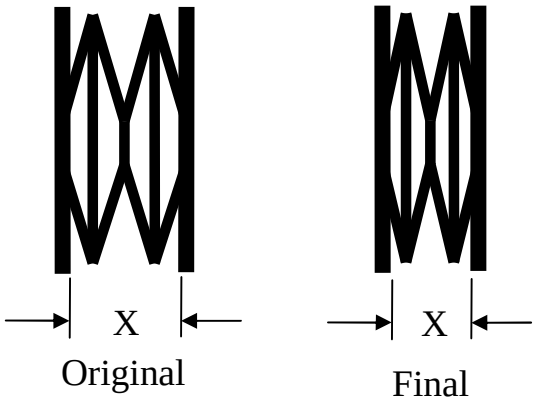
Repeat section **(2.3.9)** so that each bolt is turned approximately 2/3 of the total number of turns as shown in the spreadsheet, and then the full number of turns, using the following bolt tightening pattern for the second and third pass through the bolt tightening sequence:

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

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

Keep a table of distances for each bolt on each pass. Also keep a table of the top and bottom crush plate / prop extension distance measurements, either on paper or in the tab of the spreadsheet.

You should have obtained **APPROXIMATELY** the amount of compression indicated in the **"Total Belleville Washer Compression Target Measurement"** line of the spreadsheet. This means that overall distance between the wide area washers should be that much distance **LESS** than it was in section **(2.3.8.1).** This will indicate the appropriate amount of compressive force on the Belleville washers and prop hub.



NOTE #1: If you did not achieve the **"Total Belleville Washer Compression Target Measurement"** requirement (within 5% or so), continue to tighten the bolts as required until you meet the compression target.

NOTE #2: If you have not reached the Propeller MFG's recommended torque measurement for any of the propeller bolts, continue tightening that particular bolt until the bolt torque recommended level is achieved.

2.3.11) Bolt Tightening – Caution:

Always ensure that the washer compression is such that neither the spreadsheet "**Washer Percentage Compression**" level turns red nor the "**Compressive Stress Margin**" turns red except to the extent indicated in section **(3.1).**

Having either of these issues indicated (too high 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) Notification

If you desire, you can let me know when you've done this and email me a picture of the setup, as well as all of your tabular data (hopefully in a MS Excel spreadsheet, but I'll take whatever you've got).

3.5) 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.

3.6) Post Flight Measurements

On each of the first couple of flights, measure the washer compression (distance between the large area washers) as in the previous steps and write it down. Do the same after 5, 10, 25, 50 hours of operation, and at every condition inspection thereafter at a minimum, to check and verify for any changes.

4) Conclusions:

4.1) ½ in. Bolts:

With a nominal **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 leads to different numbers than those shown above, that's OK – use **YOUR** "**Turns**" and "**Compression**" numbers as references for future measurements.

Over time, we shouldn't ever see that 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 "Turns" and "Compression" numbers will be different.

If **YOUR** installation configuration leads to different numbers than those shown above, that's OK – use **YOUR** "**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.
7/16 inch	720125177	1.25”	17-7PH SS	0.022”	0.125”	4500 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 **2.3.10)** 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 **2.3.9.1)** and **2.3.10)** to reflect usage of torque wrenches and torque measurements **3.** Change safety wire requirement to recommendation in **3.2)**	06/21/15