

NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594



October 31, 2018

MATERIALS LABORATORY FACTUAL REPORT

Report No. 18-074

A. ACCIDENT INFORMATION

Place : Arlington, Indiana
Date : July 6, 2018
Vehicle : Bell 47G-2
NTSB No. : CEN18FA258
Investigator : Jennifer Rodi, AS-CEN

B. COMPONENTS EXAMINED

Main rotor transmission housing assembly components.

C. DETAILS OF THE EXAMINATION

Overall views of the submitted main rotor housing assembly components are shown in figures 1 and 2. The eight attachment bolts for attaching the pieces of the housing, ring gear, and freewheeling gear are shown, and the corresponding attachment locations are numbered counterclockwise as viewed from above, consistent with markings noted on the as-received components. The threads on 6 of the attachment bolts were fractured, and the corresponding nuts were separated from the bolt. Nuts remained in place on attachment bolts 1 and 7. A fractured piece of the lower housing remained attached at the bolt 1 location. Attachment bolts 3, 4, and 5, a washer, and a lock nut shown in figure 2 were received separated from the housing assembly pieces shown in figure 1.

According to the Illustrated Parts Breakdown (IPB) document for the Bell 47G-2 helicopter as provided by a representative of Scott's Bell, Inc., the attachment bolts holding pieces of the main rotor transmission housing together consist of 6 AN5-37A bolts, 1 AN5-41A bolt, and 1 AN5-44A bolt. The AN5-41A and AN5-44A bolts are located at positions 7 and 8, respectively, as labeled in figure 1. Each of the bolts in the IPB has a NAS679A5 nut. The 6 AN5-37A bolts are each installed with 1 AN960-516 washer under the head and 1 AN960-516L washer under the nut. The AN5-41A and AN5-44A bolts are each installed with 1 AN960-516 washer under the head and another AN960-516 washer under the nut.

On the accident pieces, 1 washer was observed under the head of each of the attachment bolts at locations 1, 2, 7, and 8. A washer was also included with attachment bolt 4, but not with bolts 3 and 5. Bolts 1 and 7 had nuts remaining in place on the threaded end of the bolt, and 2 washers were observed under the nut on each bolt. The thickness of all remaining washers except one under the head of attachment bolt 7 was

approximately 0.060 inch, consistent with an AN960-516 washer. The washer under the head of attachment bolt 7 was approximately half the thickness of the other washers, consistent with an AN960-516L washer.

The lower surface of the freewheeling gear was examined where it mated to the lower transmission housing. Areas of slight fretting damage and material transfer were observed near attachment holes 3 through 8. The lower edge of attachment bolt hole 5 in the freewheeling gear was deformed inward consistent with contact with the attachment bolt grip.

Manufacturer marks were noted on each of the attachment bolt heads, and the observed markings are listed in table 1. In most cases, layers of gray, yellow, and white paint were removed by scraping and/or sanding to facilitate viewing of the head markings. A question mark in the listing for bolt 2 indicates the presence of an illegible mark nested within the legs of the X in that bolt head. As noted in table 1, each bolt had a different manufacturer mark.

Table 1. Attachment Bolt Markings and Measurements

Position	Head Marking	Shank Length (inch)	Length from under Head to Last Intact Thread (inch)	Grip Diameter (inch)	Thread Major Diameter (inch)
1	C X S	4.004	All intact	0.3083	0.3070
2	X ?	3.923	3.588	0.3076	0.3014
3	X L ^E	3.858	3.512	0.3091	0.3032
4	ROCKFORD + SPCo	3.877	3.549	0.3105	0.3064
5	R X M	3.976	3.709	0.3093	0.2991
6	L X S C	3.950	3.596	0.3095	Not measured – damaged
7	X OIDO	4.255	All intact	0.3085	0.3078
8	K X R	Not measured – bent shank	Not measured – bent shank	0.3096	Not measured – damaged

Two different styles of nuts were observed. The nut on attachment bolt 7 was shaped consistent with a NAS697 style locknut. The nut on attachment bolt 1 and the separated nut had a shape consistent with a MS21042 style locknut. According to a substitution table in specification MS21042, nut MS21042L5 is a substitute for a NAS679A5 nut.

The attachment bolts were further examined. Attachment bolt 2 was removed from its attachment hole by hand to facilitate further examination of that attachment bolt. The nuts were removed from attachment bolts 1 and 7, but the bolts were slightly bent, preventing their removal from the housing. Attachment bolt 6 was also slightly bent, and attachment bolt 8 was substantially bent, preventing their removal as well.

Bolt dimensions including shank length, grip diameter, and thread major diameter were measured on each of the bolts where possible as listed in table 1. The shank length of bolt 8 was not measured due to the extent of bending deformation. Most of the bolts had at least several intact threads adjacent to the shank, and the thread major diameter was measured on the intact threads. However, thread peaks of intact threads on bolts 6 and 8 were damaged consistent with contact with the lower housing, and the major diameter was not measured for those threads.

As listed in table 1, shank length varied from 3.858 inches as measured on bolt 3 to 4.255 inches measured on bolt 7. According to Military Specification Sheet Number AN3 to AN20, the AN5-37A bolt (bolts 1 through 6) should have a shank length of 3.953 inches to 4.000 inches. The AN5-41A bolt (bolt 7) should have a shank length of 4.203 inches to 4.250 inches. The shank length of bolt 3 was within the range of an AN5-36A bolt, which has a specified shank length of 3.828 inches to 3.875 inches.

The grip diameters measured on each of the bolts ranged from 0.3076 inch on bolt 2 to 0.3105 inch on bolt 4. According to the military specification for AN5 bolts, the specified grip diameter ranges from 0.309 inch to 0.312 inch.

The threads for each of the attachment bolts were examined, and many of the threads were covered with grease and oil deposits. After an initial examination and photography, the oily deposits were wiped from the threads using a cloth. Bolts 2 through 5 were further cleaned using an ultrasonic cleaner while submerged in a solution of Alconox detergent and water followed by brushing with a soft-bristle brush. After cleaning, greasy deposits remained in the thread roots of intact threads. Next, the bolts were submerged in a degreasing system with agitation for several hours. Most of the grease deposits were removed as shown the upper images of figures 3 through 6 showing the threads for bolts 2 through 5 after cleaning. Additional grease deposits were scraped from the thread roots of bolts 2 and 4 using a scalpel to reveal the full thread profile in those bolts as shown in the lower images in figures 3 and 5.

Upon examination, the attachment bolts had varying numbers of intact and sheared threads. On bolts 1 and 7, all threads were intact. The remaining bolts 2 through 6 and bolt 8 had 1 to 5 intact threads adjacent to the grip, but the thread peaks were at

least partially flattened and smeared consistent with contact with the corresponding lower housing attachment hole bore. The remainder of the threads in bolts 2 through 6 and bolt 8 were fractured near the thread roots, and the fracture surfaces were smeared consistent with shear fracture from contact with the corresponding threads of the nut. Brackets in figures 3 through 6 indicated where sheared threads were observed on bolts 2 through 5. Sheared bolt threads remained trapped within the separated nut shown in figure 2. Bolt 5 had 5 mostly intact threads adjacent to the grip. Bolts 3 and 4 had 4 mostly intact threads, and bolt 2 had 3 mostly intact threads. Bolt 6 had 2 mostly intact threads, and bolt 8 had 1 mostly intact thread.

The distance from the underside of the bolt heads to the middle of the last (furthest from the grip) intact thread was measured, and results are listed in table 1. The lengths in bolts 2 through 6 (all specified as AN5-37A bolts) ranged from 3.512 inches in bolt 3 to 3.709 inches in bolt 5. For comparison, the distance between the underside of the bolt 1 bolt head to the clamping face of the nut measured 3.606 inches (as measured before the nut was removed).

Closer views of the threaded ends of bolts 2 and 3 are shown in figures 3 and 4. In both cases, intact but damaged threads were observed between the shank and the completely sheared threads. As shown in figures 2 and 3, the pressure flanks of 1 to 3 of the mostly intact threads were deformed and missing with a profile shape corresponding to the nut thread peak profile. Circumferential sliding contact marks were observed in the contact surfaces of the damaged pressure flanks where the deformed and missing bolt thread was observed.

Closer views of the threaded ends of bolts 4 and 5 are shown in figures 5 and 6. The pressure flanks on several intact threads on bolt 5 had circumferential contact marks as indicated with unlabeled arrows in figure 6 but appeared free of substantial deformation or missing material. The pressure flanks of the intact threads on bolt 4 were free of circumferential contact marks or circumferential contact damage.

The thread form specified for AN5 bolts is 5/16-24 UNF-3A. According to Machinery's Handbook, Twenty-sixth Edition,¹ the major diameter of the thread ranges from 0.3053 inch to 0.3125 inch. The angle between adjacent thread flanks of the specified thread is 60 degrees. The individual thread depth is 0.02481 inch, and the maximum minor diameter is 0.2629 inch. The pitch (thread spacing) is 0.04167 inch, and at the major diameter the external thread peak has a width of 0.125 times the pitch (0.0052 inch). Following the thread form with flanks at 60 degrees and a peak width of 0.0052 inch at a diameter of 0.3125 inch, the width of the thread at a major diameter of 0.3053 inch is calculated to be 0.0094 inch.

The major diameters as measured using a micrometer on intact threads are listed in table 1. However, it should be noted that the measured condition may not reflect the original thread diameter due to use, contact wear, and accident damage. As measured, bolts 2, 3, and 5 had major diameters that were less than the specified minimum major

¹ Machinery's Handbook, 26th Edition, Industrial Press, Inc., New York, New York (2000).

diameter of 0.3053 inch. None of the bolts had major diameters that exceeded the maximum value of 0.3125 inch.

The inside (minor) diameter of the nuts removed from bolts 1 and 7 were measured. The inside diameter of the nut removed from bolt 1 measured 0.267 inch to 0.277 inch. The inside diameter of the nut removed from bolt 7 measured 0.2695 inch to 0.272 inch. According to Machinery's Handbook, the minor diameter of a 5/16-24 UNF-3B thread (nut thread) is 0.2670 inch to 0.2754 inch.

Dimensional measurements were taken on the intact thread profiles of bolts 2 through 5 using a Keyence microscope, and resulting measurements of thread depth, flank angles, and peak width are shown in figures 7 through 10. For bolts 2 and 3, the flank angle measurements were approximated based on limited remaining thread in some cases where missing material was observed on the pressure flank. Thread peak width was also approximated in threads where missing material was observed using the intersection between the flank angle measurements and an imaginary line parallel to the thread peaks. Average values for each measurement are listed in table 2.

Bolts 3 through 5 had thread profile measurements that were generally comparable to the thread specification given the limited precision of the measurements and estimations made due to thread damage and use. However, measured values for bolt 2 showed larger deviations from the specified thread profile. The average flank angle for bolt 2 was approximately 11 degrees less than the specified angle of 60 degrees. The average thread depth for bolt 2 was 0.0055 inch less than the specified value of 0.02481 inch. Finally, the average width of the thread peaks in bolt 2 was approximately double the maximum thread peak width calculated from the thread form at the minimum major diameter of 0.3053 inch. The thread peaks for bolt 2 had a gold hue consistent with the original plating, indicating variations in thread depth and peak width were not due to wear or damage to the thread peak.

Table 2. Bolt Thread Profile Measurements

Bolt number	Average Flank Angle (degrees)	Average Thread Depth (inch)	Average Peak Width (inch)
2	48.9	0.0193	0.0193
3	60.7	0.0230	0.0100
4	58.9	0.0268	0.0073
5	63.0	0.0238	0.0087

Transverse cuts were made through the shanks of bolts 2 through 5 to facilitate hardness testing of the bolts. The cut sections were then ground to a 2400-grit finish and tested using Rockwell tester. The hardness was then determined from the average of 5 indents on each prepared cross-section. The average hardness was 51.2 HR30N, 51.1 HR30N, 51.4 HR30N, and 51.8 HR30N for bolts 2, 3, 4, and 5, respectively.

According to Military Specification Sheet Number AN3 to AN20, the AN5-series steel bolt should have a rated ultimate strength of 6,500 pounds in tension. According to Machinery's Handbook, the tensile area of a 5/16-inch bolt is 0.0625 square inch. Dividing the bolt rated strength by the tensile area, the tensile strength of the steel should be at least 104,000 pounds per square inch. According to ASTM Standard A370-12a,² a hardness of 51.3 HR30N in ferritic or martensitic steels generally corresponds to a tensile strength of approximately 146,000 pounds per square inch.

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² ASTM International Standard A 370 – 12a, "Standard Test Methods and Definitions for Mechanical Testing of Steel Products," *Annual Book of ASTM Standards*, ASTM International, West Conshohocken, Pennsylvania (2014).

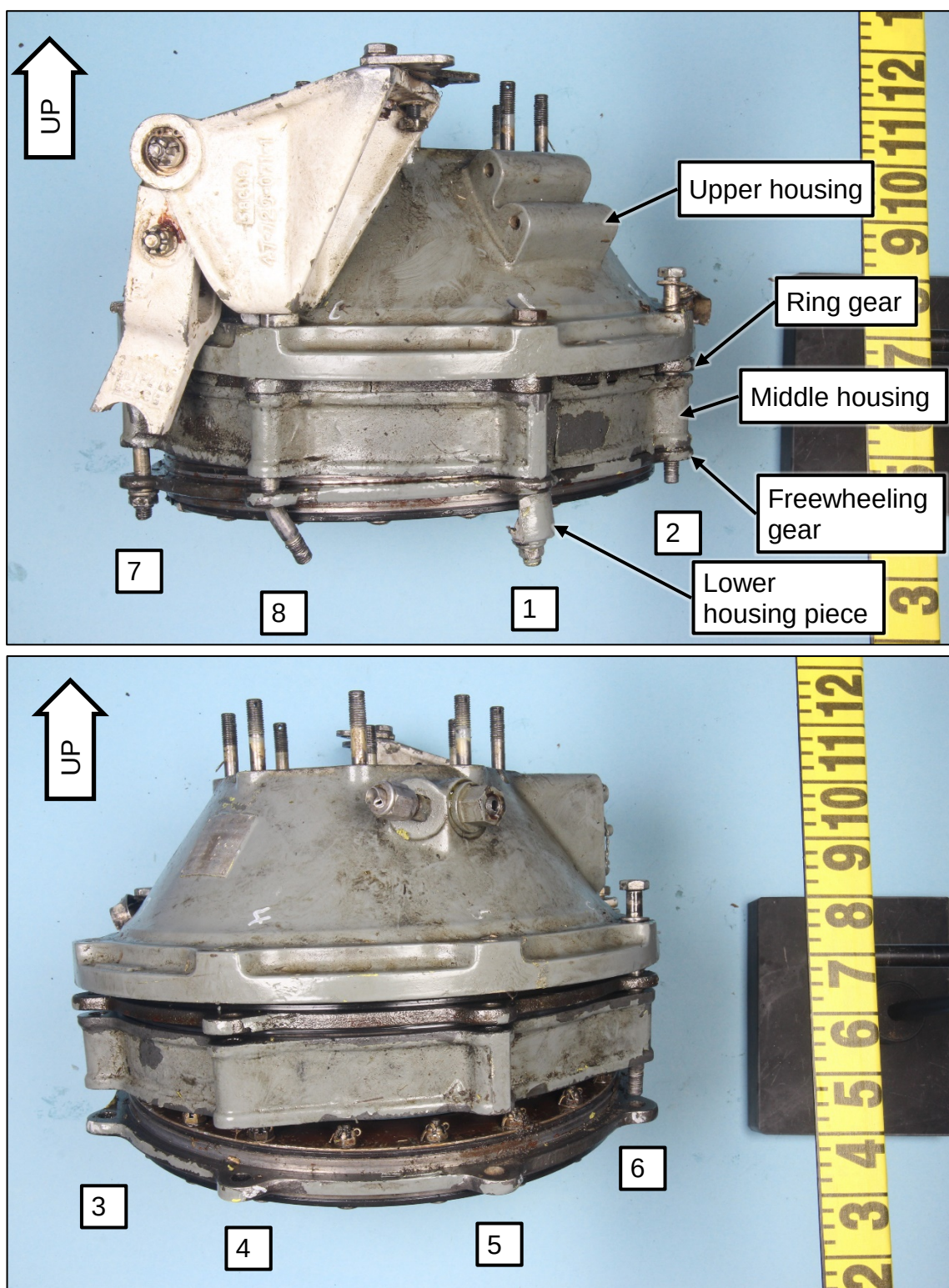


Figure 1. Overall views of the main rotor transmission assembly components as-received.



Figure 2. Overall view of main rotor housing assembly attachment bolts, washer (on bolt 4), and nut received separately.

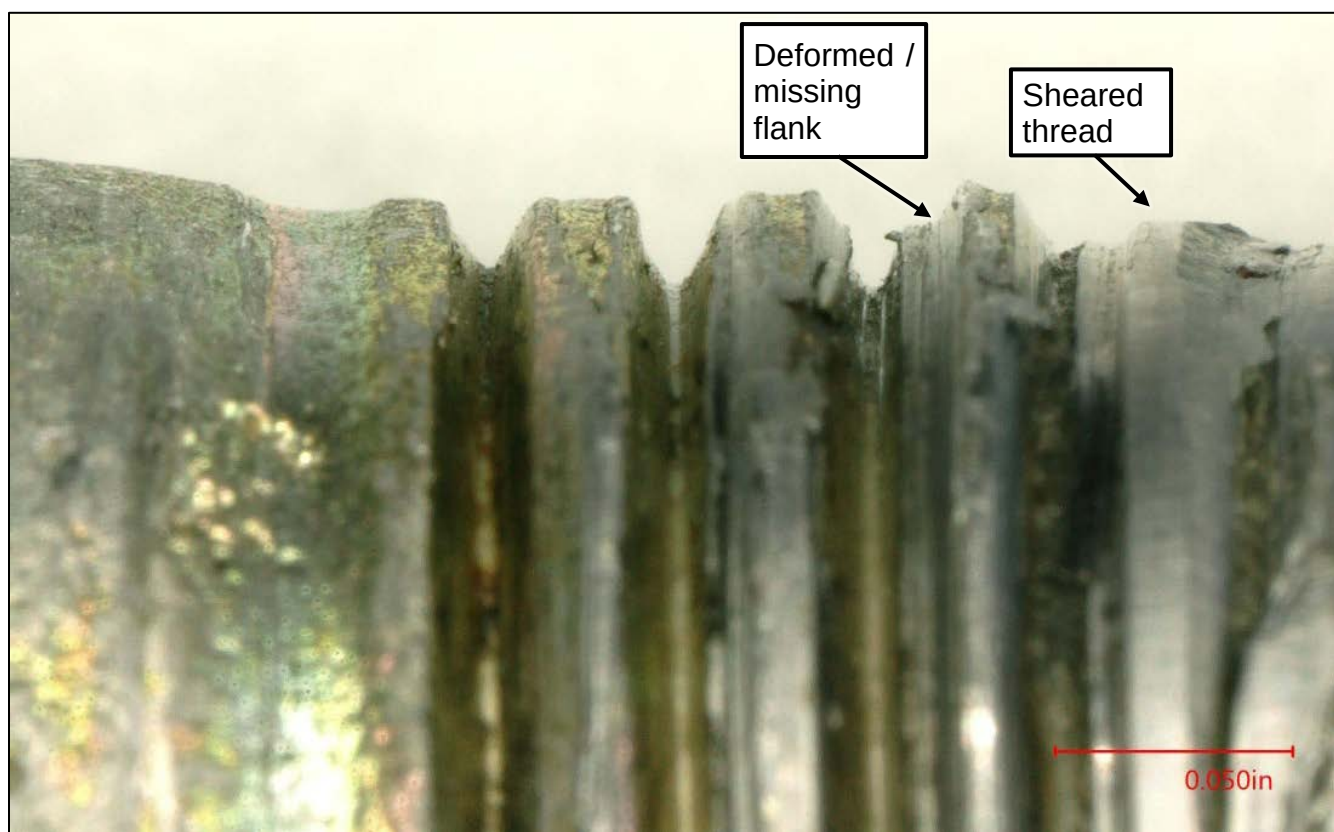
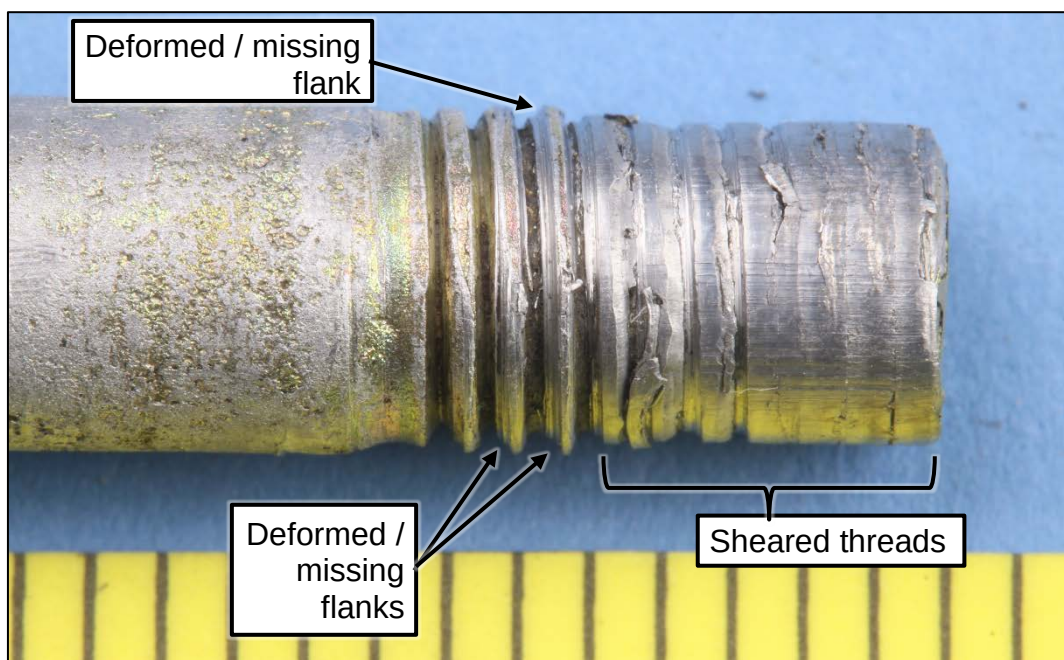


Figure 3. Close views of attachment bolt 2 threads after cleaning and degreasing.

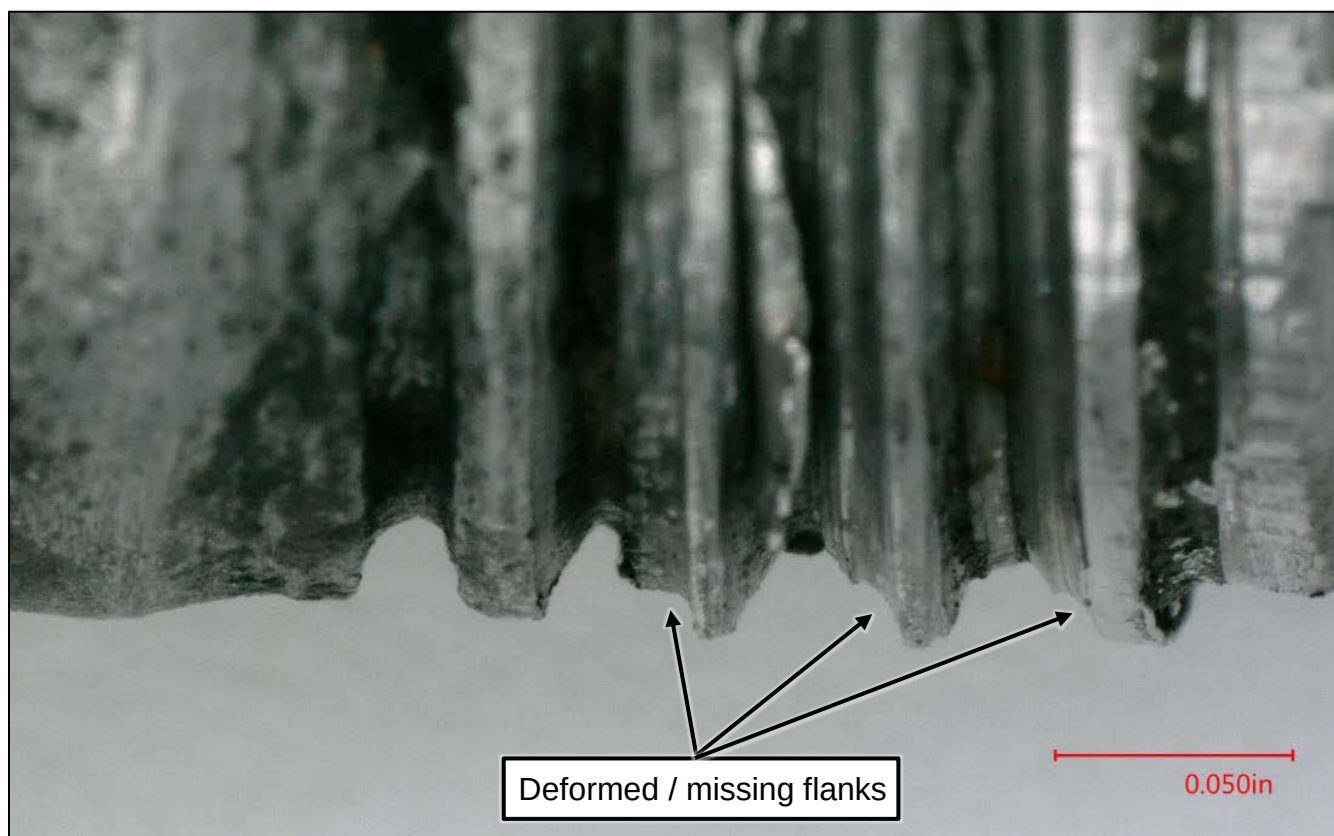
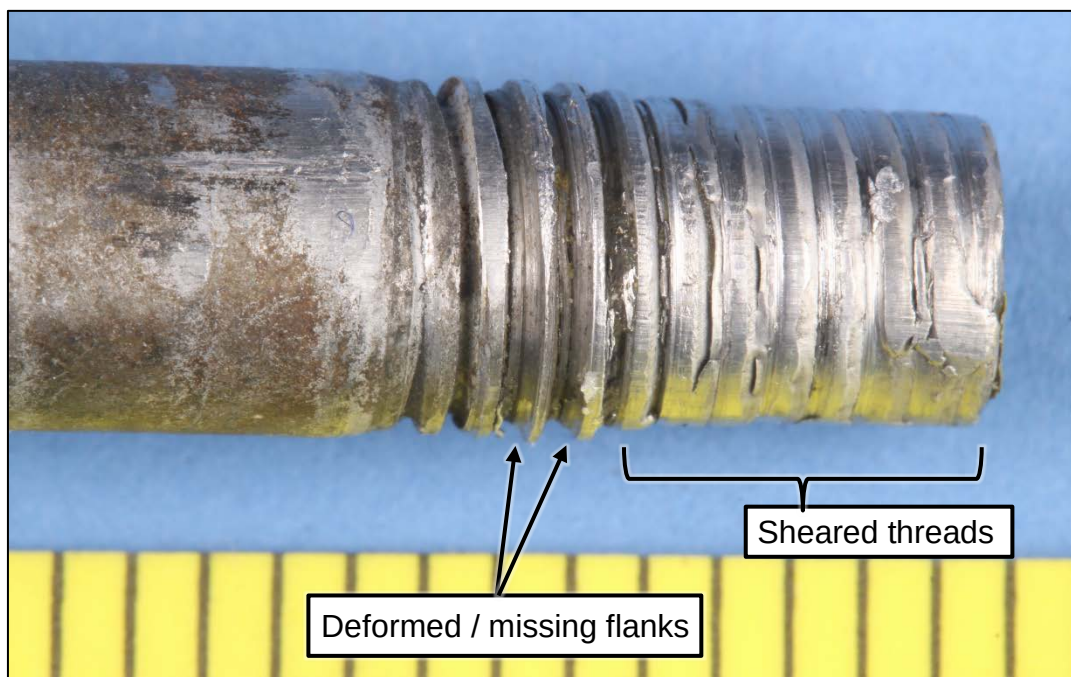


Figure 4. Close views of attachment bolt 3 threads after cleaning and degreasing.

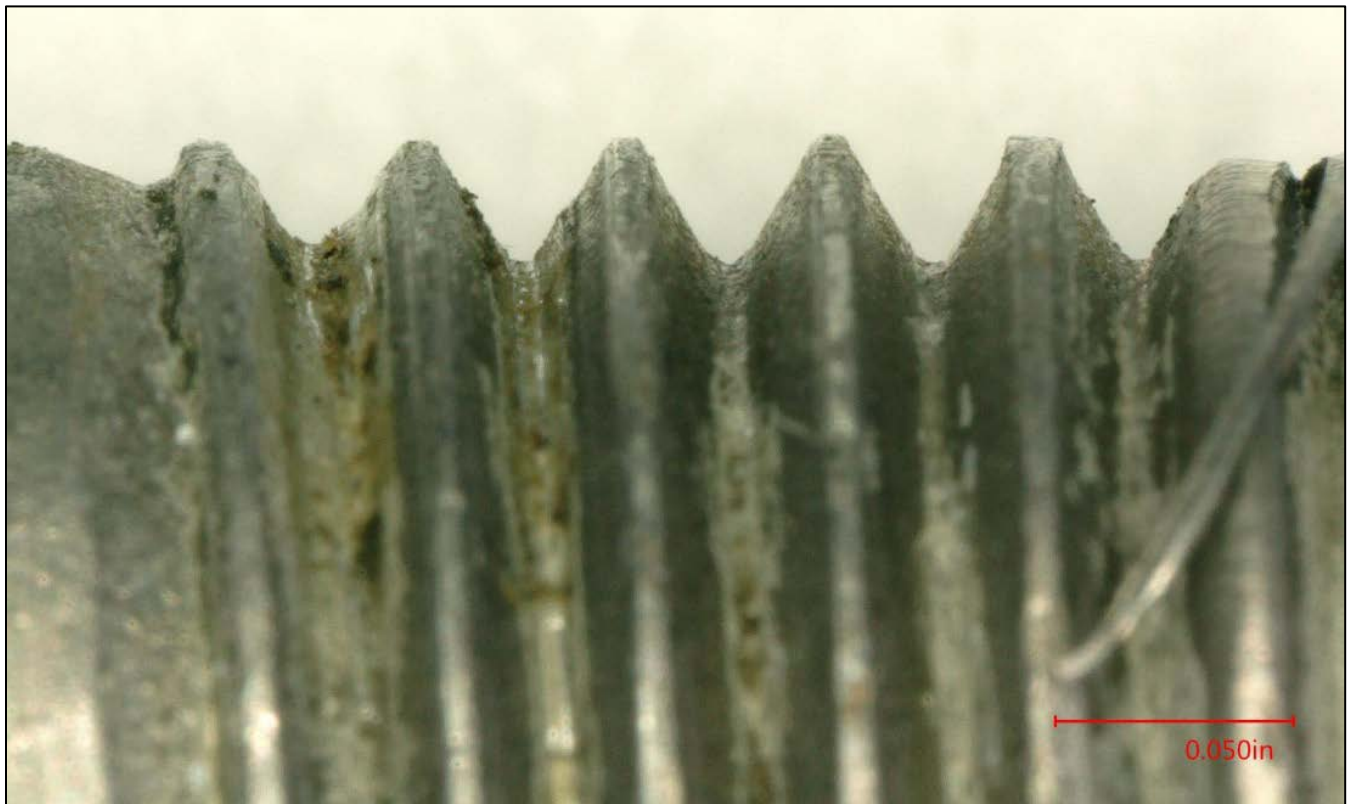
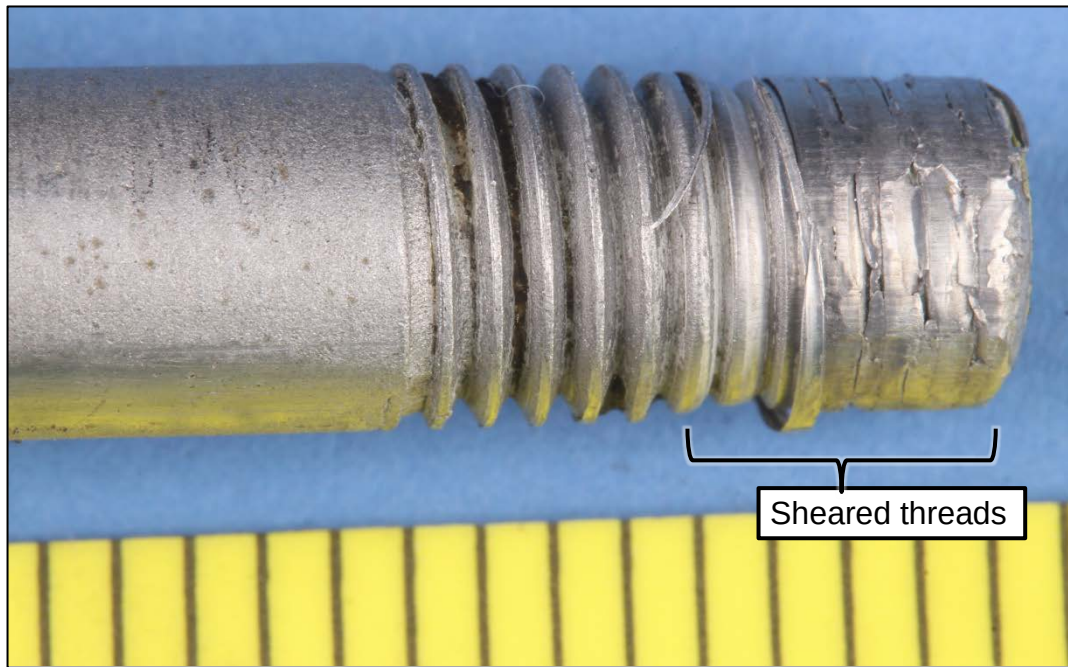


Figure 5. Close views of attachment bolt 4 threads after cleaning and degreasing.

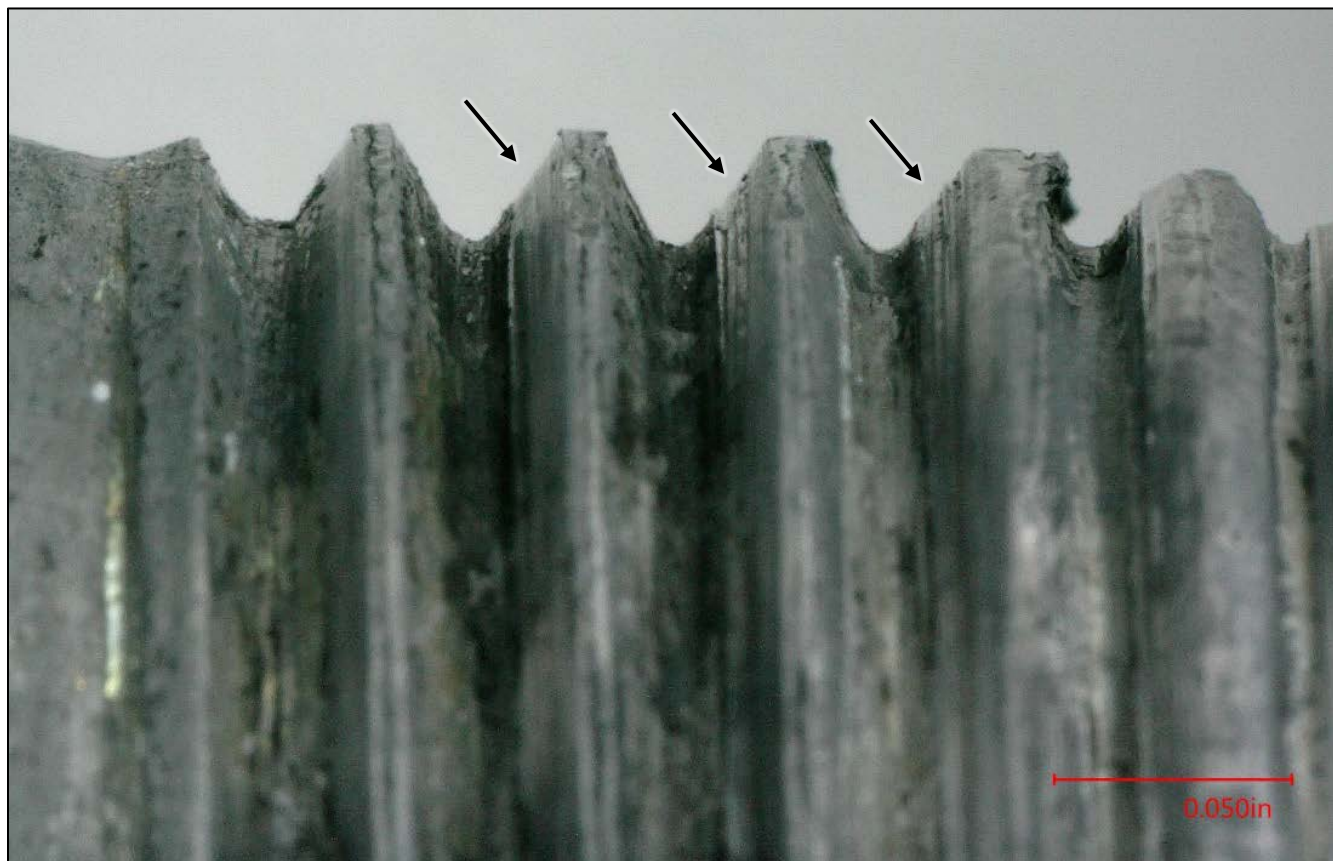
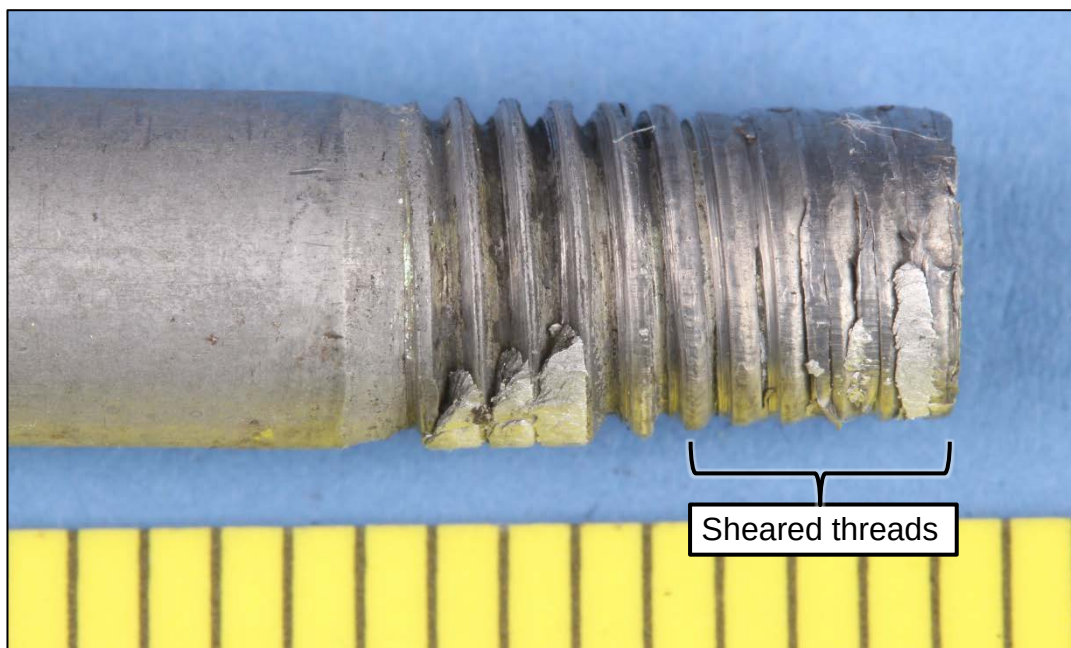


Figure 6. Close views of attachment bolt 5 threads after cleaning and degreasing. Unlabeled arrows point to circumferential sliding contact marks on pressure flanks of the threads.

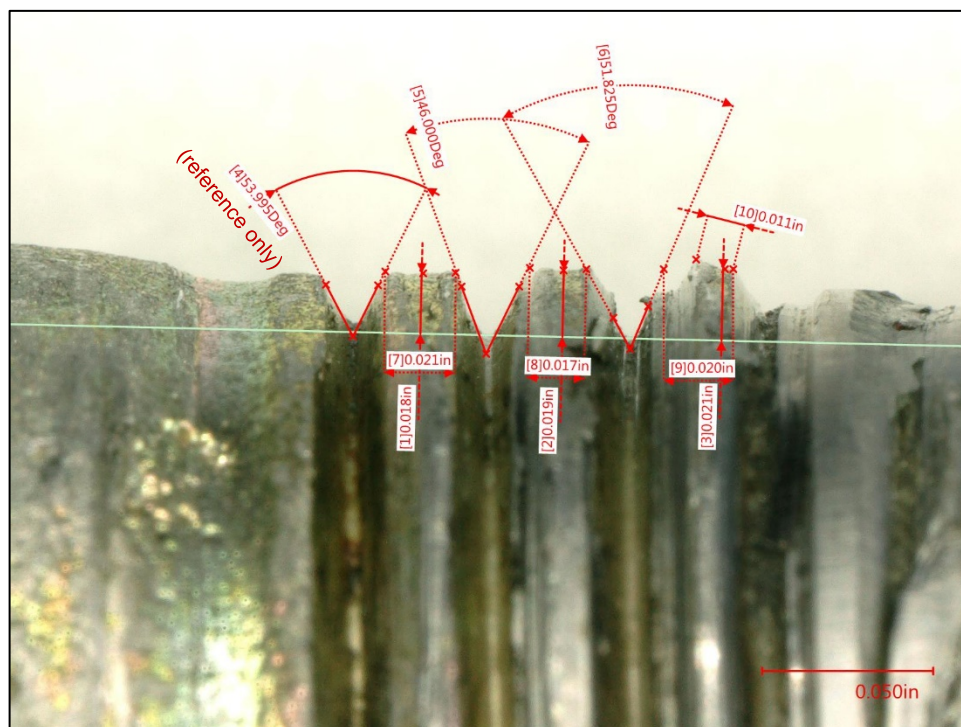


Figure 7. Thread profile measurements on intact threads on bolt 2.

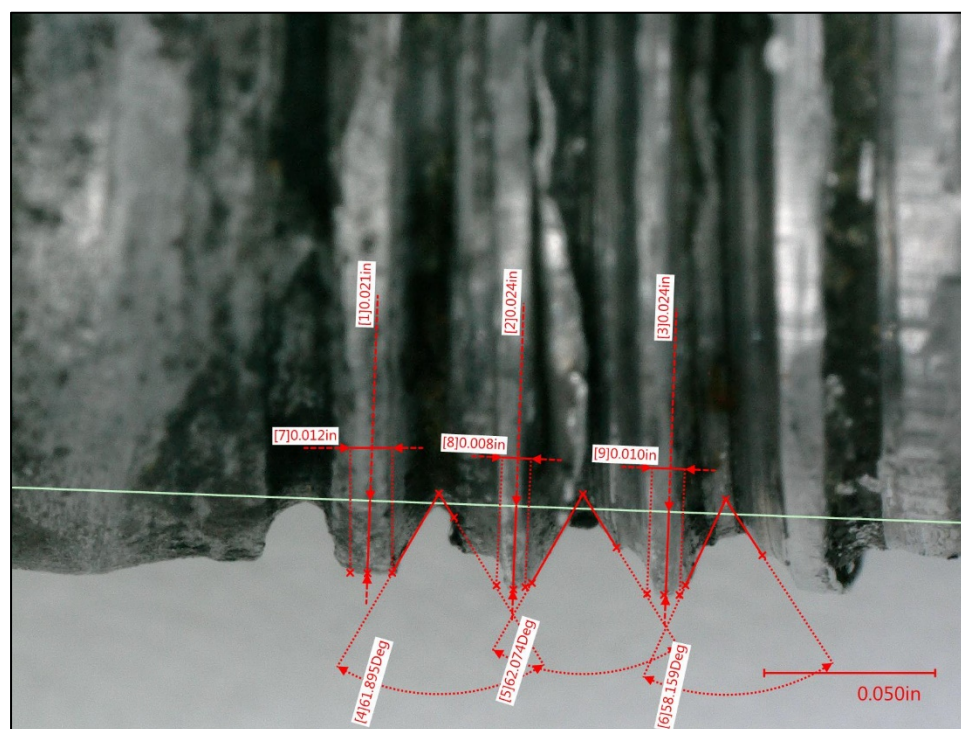


Figure 8. Thread profile measurements on intact threads on bolt 3.

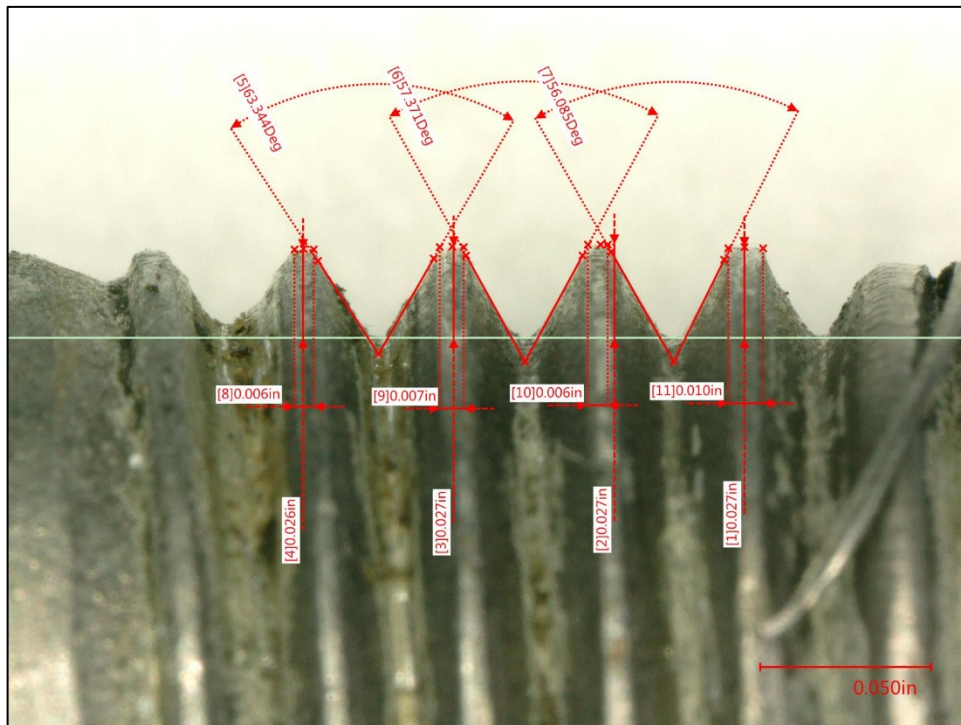


Figure 9. Thread profile measurements on intact threads on bolt 4.

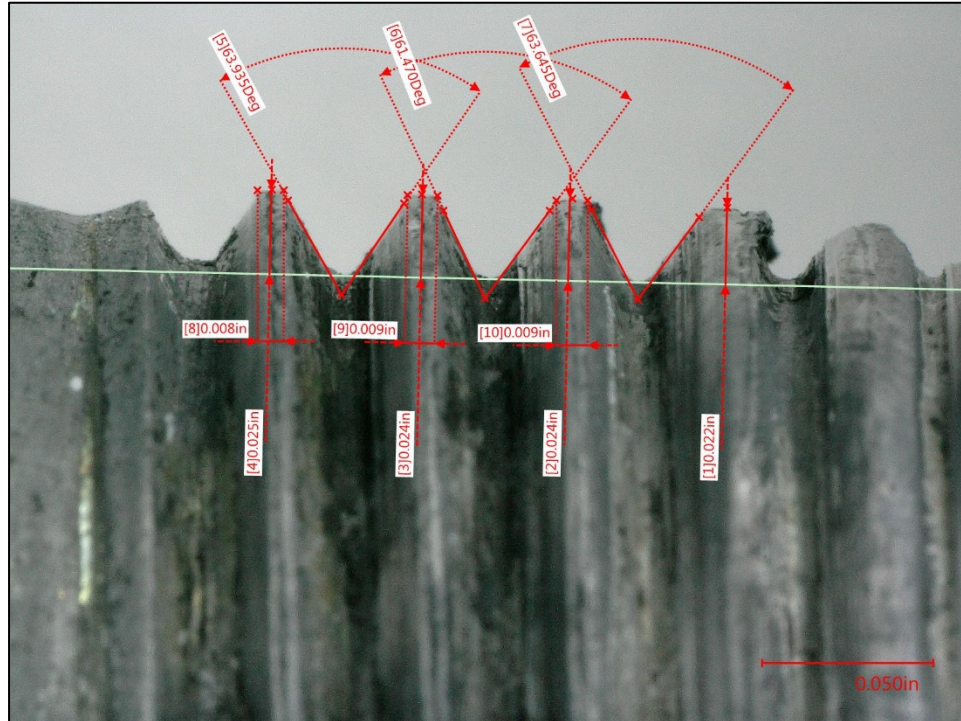


Figure 10. Thread profile measurements on intact threads on bolt 5.