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ASA 261 HS Jackscrew
Gimbal Nut
Thread Remnant Formation
Study

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1.0 INTRODUCTION

The Alaska Airlines flight ASA 261 post accident inspection of the horizontal stabilizer jackscrew ACME nut revealed that the threads were completely stripped out. Remnants of the ACME nut threads were discovered around the ACME screw. A cross section of the thread remnant is shown in Figure 1.1 (Reference NTSB Materials Laboratory Report no. 00-145). The NTSB metallurgist indicted that this was a typical cross section of the recovered remnants. This cross section is shown overlaid on a 0.08 inches worn ACME nut thread in Figure 1.2. A hypothetical sequence of worn geometry is shown in Figure 1.3. Note at 0.08 inches of wear, the tip of the thread stopped wearing while the rest of the face continued wearing. At 0.13 inches of wear, the wear area is reduced to only a small area at the root of the thread.

This report documents the work done to characterize how the shape of the thread remnant was formed during the wearing process of the ACME nut thread and to estimate the maximum amount of wear to the threads while maintaining ultimate load capability. This report gives detailed information on the characterization of the thread formation and will only refer to analysis results that lead to this characterization. This analysis is of an extremely worn ACME nut that does not occur typically in service.

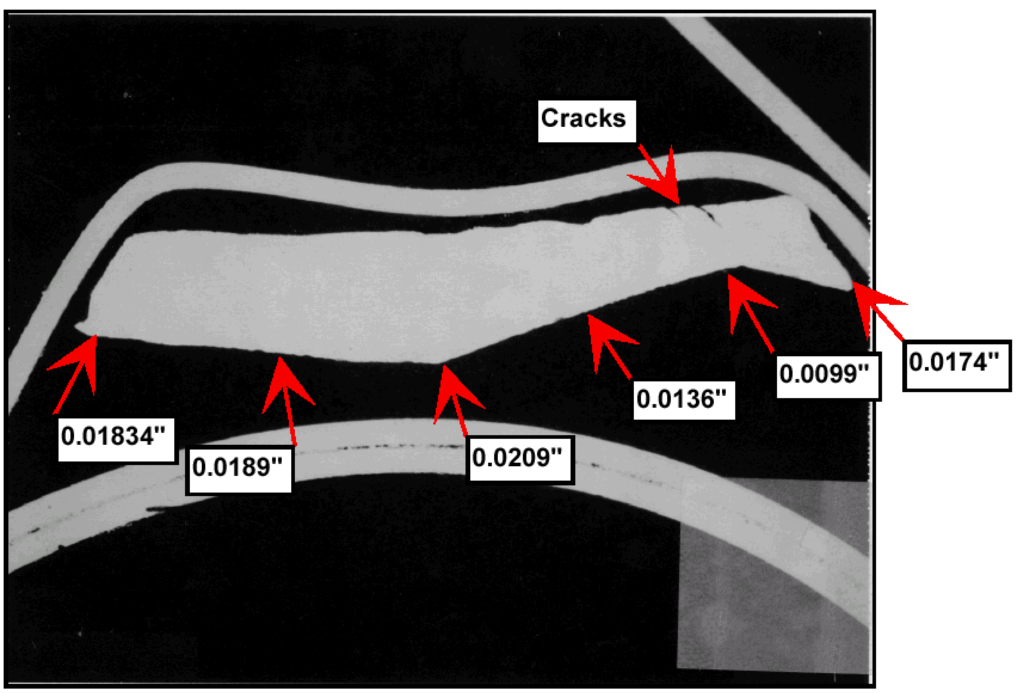

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Figure 40--Radial metallographic cross section through remnant #6 showing a similar cross section as that seen during SEM examinations. Note the slight curvature of the flat surface (top). View is reversed with shear fracture at right. Thickness dimensions are noted at selected locations.

Figure 1.1 thread remnant cross section

1.0 INTRODUCTION (continued)

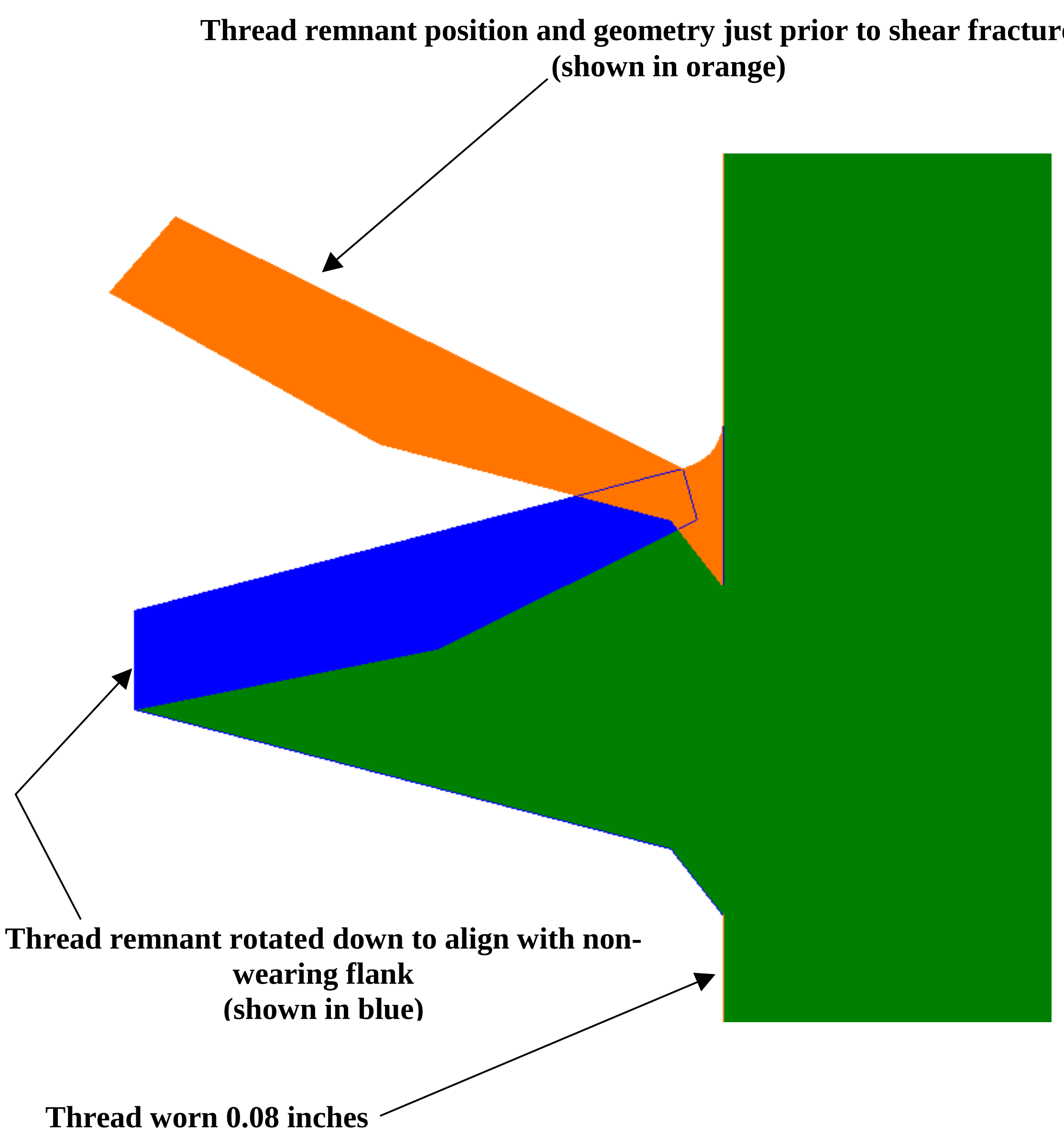

Figure 1.2 Thread remnant overlay

1.0 INTRODUCTION (continued)

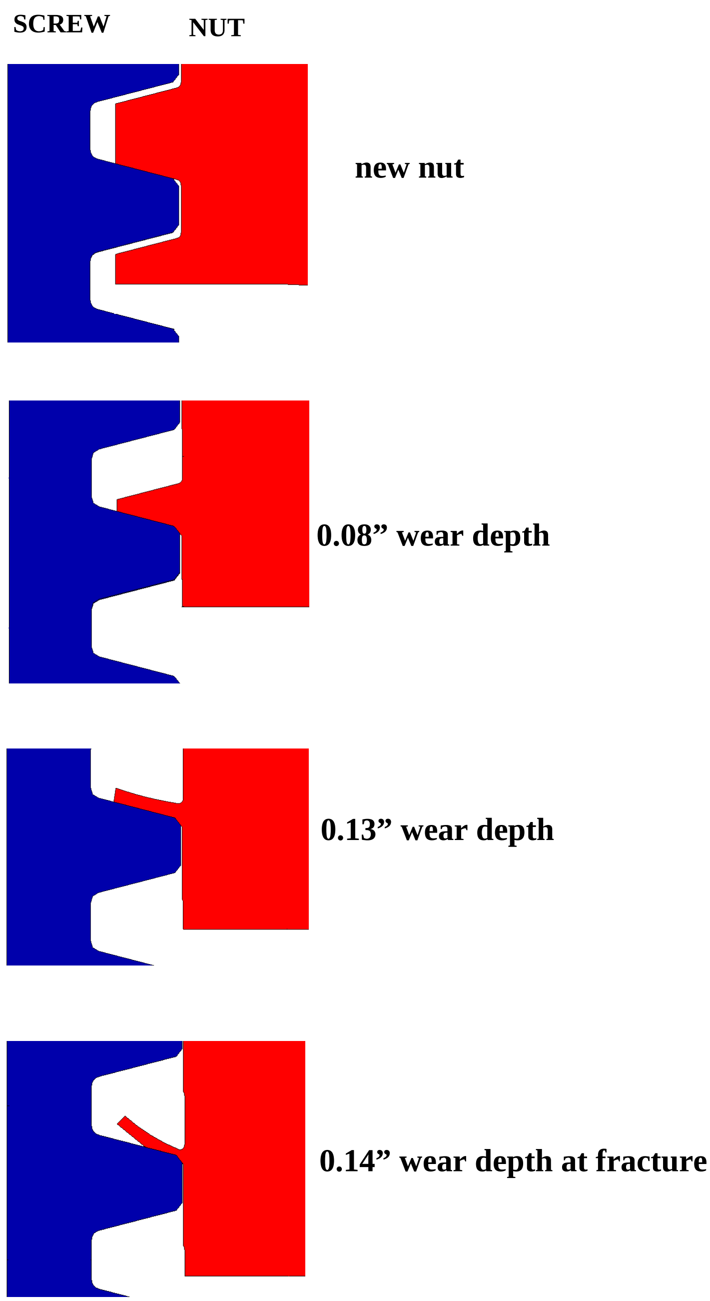

Figure 1.3 Proposed wear sequence based on thread remnant geometry

1.1 BACKGROUND

The thread remnant indicates that the tip stopped wearing at about 0.08 inches of wear[1]. Since the ACME screw remained unchanged, the nut threads deformed to bend the tip away from the screw flank and prevented wear.

The initial work was to build a complete nut model with 32 threads worn to the 0.08 inches of wear level. An axisymmetric model was used for this analysis. Attempts at 3-D helical thread models were found to require a prohibitive amount of computing resources to solve. The axisymmetric model simplifies the threads by simulating them as “doughnuts” rather than helices. This was considered acceptable because the torsion effects were assumed small and could be added later, if necessary. The ACME nut wall thickness varies greatly depending on the orientation of the section. Models were built comparing the two extremes in thickness. The thicker nut wall concentrated more load on the first thread, and therefore was chosen for the remainder of the study.

The assembly model was built with all 32 threads identical. The actual nut probably would not have this geometry because highly loaded threads wear more. Thus, the wearing process would tend to even out the load distribution among the threads. Therefore, the model would indicate higher contact pressures and loads distributed to fewer threads than occurs on the actual nut.

From a loads perspective, the full assembly model described in section 3.0 showed that the thread stresses developed during normal operating jackscrew flight loads were too low to cause plastic deformation. The assembly model indicated that from 3 to 32 threads, depending on the load level and temperature, would be effective in supporting the jackscrew loads. High operating flight load levels did not plastically deform the threads. Therefore, the model indicates that typical flight loads did not induce plastic deformation. Plots supporting these results will be included in the final assembly model results in section 3.

The next step of this study was to investigate how the thread bends while it is being worn. An axisymmetric model was built of a single thread at various wear levels. Pressure load was applied to the thread in various distributions to evaluate the effects. The thread remnant section shown in Figure 1.1 has a curved surface on the non-wearing flank. The pressure load had to be shifted toward the tip of the thread in order to reproduce that curved shape. The final version of the single thread model is described in section 2.0. The wear level described in section 2 represents the maximum amount of wear possible while maintaining ultimate load capability in the nut (0.105 inches of wear).

The last step was to repeat the single thread geometry and strain to form a complete ACME nut model. This ACME nut model was then added to a complete assembly model, which included the ACME nut, screw, quill nut and washer, and upper bearing race. This assembly model was used to determine how the load was distributed among the threads for various load levels, and finally to determine the ultimate load carrying capability of the worn ACME nut.

[1] The term “wear” in this report is describing actual material removal from new ACME nut threads. As the nut and screw threads are assembled with a .003” to .010” clearance, this amount is added to the “wear” value in order to achieve a measured end play. For example, “at about .080” of wear” would be equivalent to .083” to .090” of measured end play).

2.0 Single Thread Formation model

The final single thread formation model is shown in Figure 2.1. This model was used to simulate the changes in the thread from 0.080 to 0.105 inches of wear. This model simulated the wear by the following procedure:

1. The model was loaded with pressure on the contacting surface. The pressure load and constraints are shown in Figure 2.3.
2. The pressure load on the thread face was removed.
3. A row of elements along the wearing surface was removed. The model was built to simulate the wearing process from 0.080 to 0.105 inches in 10 steps. Comparisons were done with up to 30 steps with no significant difference from the 10 step model.
4. The resulting model deformed shape was compared with the ACME screw. The screw part of the model was displaced to represent the correct position for each amount of wear. By comparing the nut deformed shape with the ACME screw position, the amount of permanent set in the thread could be evaluated. If an adjustment was required, the procedure starts over at step 1 with a different applied pressure load. Once the ACME nut wearing flank was aligned with the ACME screw thread flank, the process would be repeated for the next row of wear elements.

The analysis was run using the ABAQUS standard finite element program. This program was chosen because it provides state of the art support for general contact, material removal, and metal plasticity. The analysis was done using QUAD4 axisymmetric elements with a reduced integration. The reduced integration was used so the equivalent plastic strains from the thread forming process could be easily included in the full nut assembly model. The screw was modeled with TRI6 elements. The screw has no load on it and just moves as a rigid body to check the nut thread shape at each wear level.

All of the model files are stored on the Boeing archive system: ufs2.ca.boeing.com

in the directory: /longbch-struct/c388057/asa261/thread-remnant

Next the model details will be explained.

2.1 Model geometry

The completed thread formation model used to simulate the wearing process from 0.080 to 0.105 inches of wear is shown in Figures 2.1 and 2.2. The complete model includes a single nut and screw thread. The ACME screw thread was included in the model only for reference to help with adjusting the load. No contact was included between the screw and the nut. The material that wears away was modeled as a wedge, shown in red in Figure 2.2. The worn material was modeled in 10 layers. At each step of wear, a single layer of elements was removed. The shape of the worn material was adjusted so that the free edge of the nut at each wear aligns with the ACME screw edge. A curve in the wearing surface was needed to get a straight edge during the wearing and deforming process.

Single Thread Formation model

2.1 Model Geometry (continued)

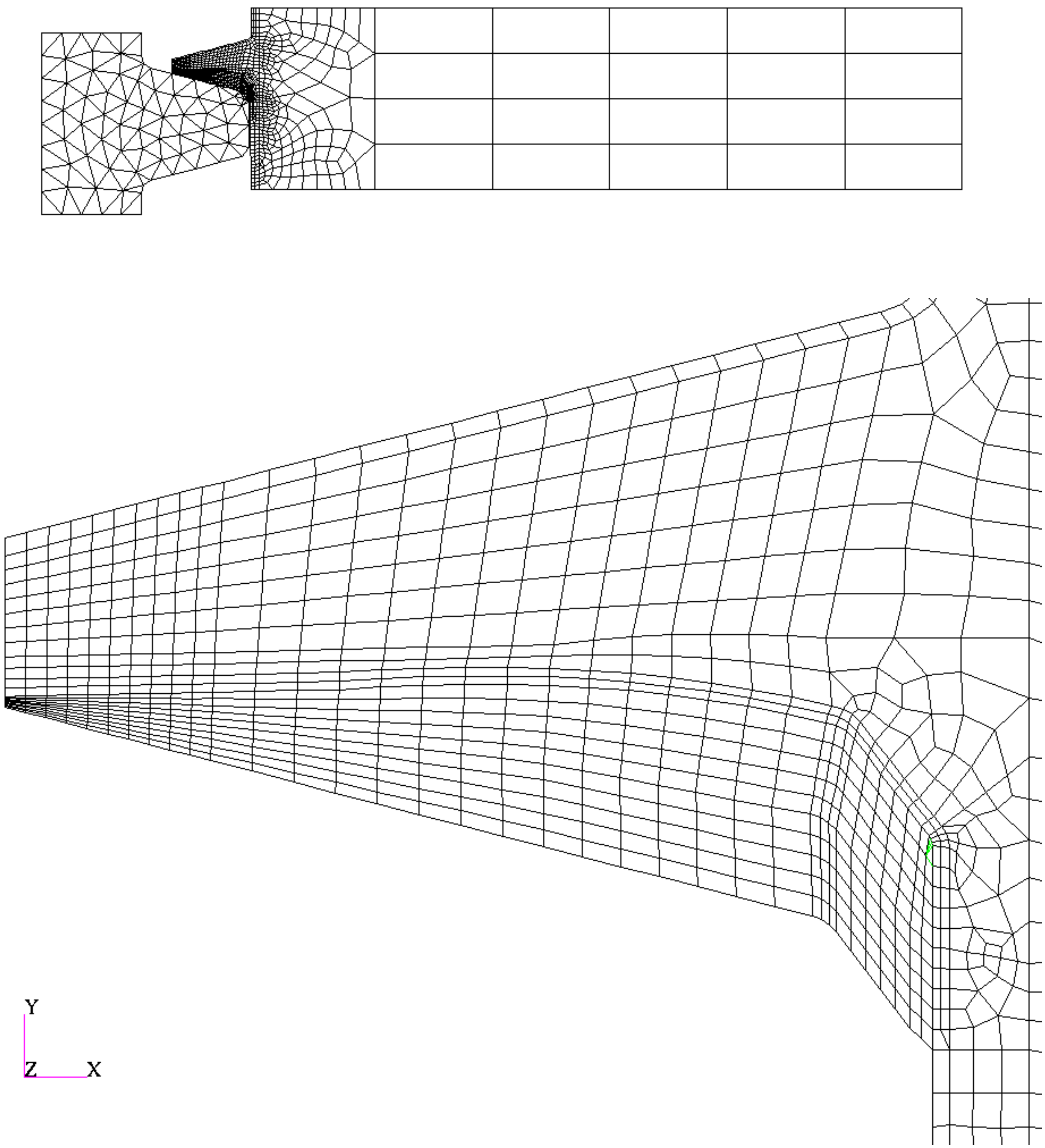

Figure 2.1 single thread model

Single Thread Formation model

2.1 Model Geometry (continued)

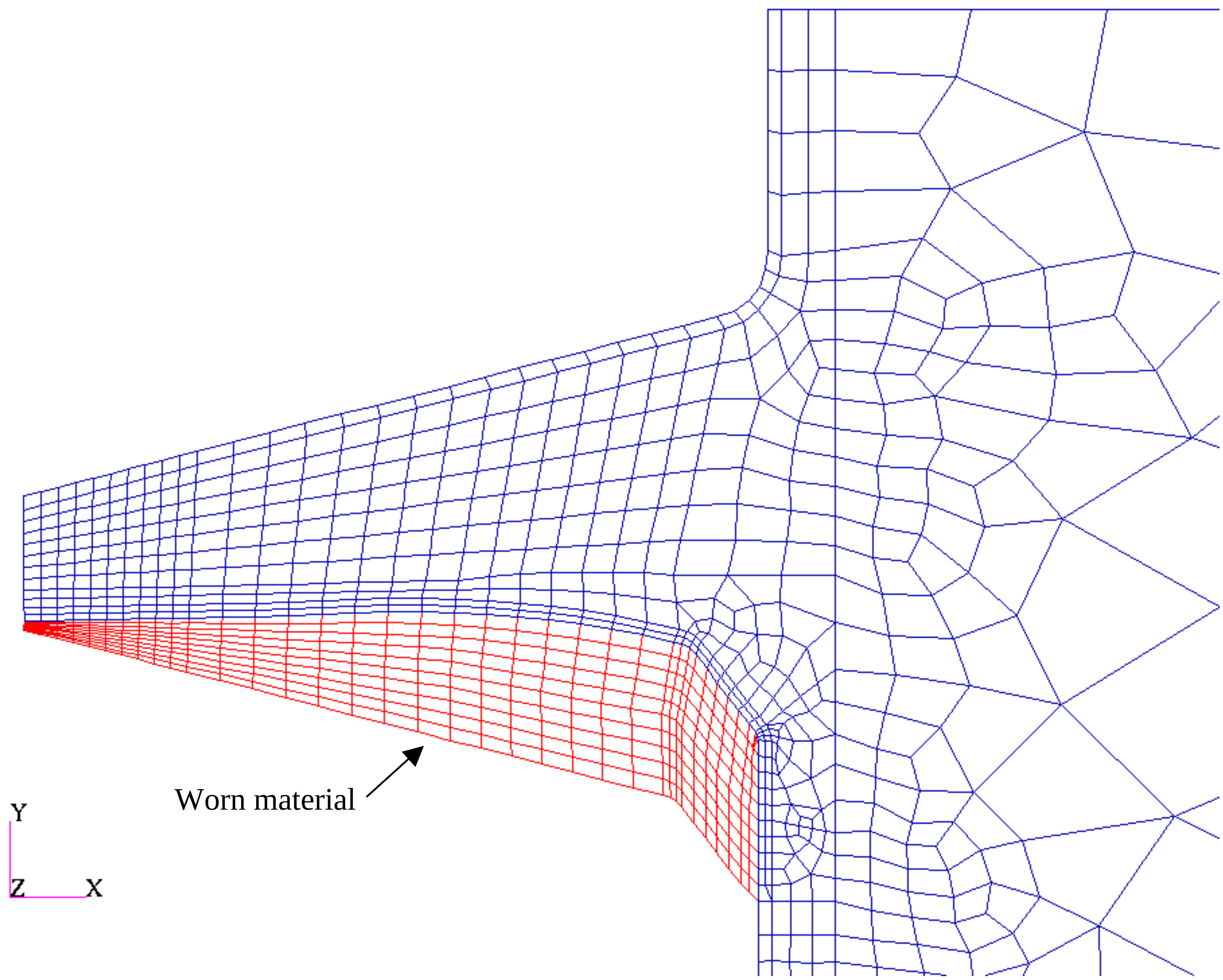

Figure 2.2 single thread model

Single Thread Formation model

2.2 Model Boundary conditions

The initial applied loads and constraints on the nut portion of the model are shown in Figure 2.3. The top of the nut wall was supported vertically only. A uniform pressure load was applied to the wearing face of the nut thread. As each row of elements was removed, the load was shifted to the next free edge. Many loading distributions were investigated. The loading profiles that cover the entire thread flank resulted in a shear type deflection of the thread. The shear type deflection resulted in a straight non-wearing flank of the thread after the wearing was completed. Since the actual thread remnant has a curve shape for the non-wearing flank, a bending type deflection was needed. In order to produce a bending type deflection, the load had to be applied toward the tip. If the load was shifted too much toward the tip, an extreme amount of curvature resulted, which also was not indicated by the actual thread shape. A uniform pressure was chosen to simplify the load adjustment process.

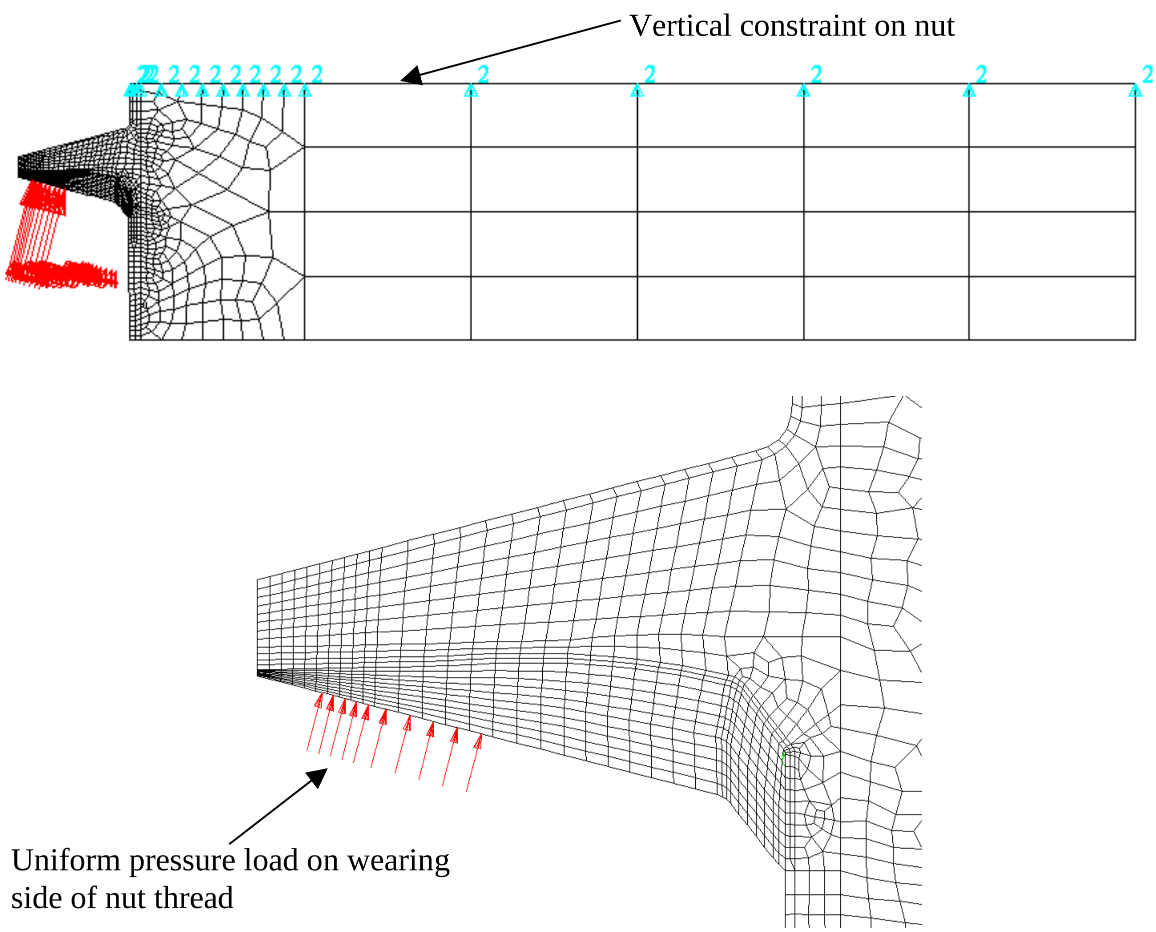

Figure 2.3 loads and boundary conditions on the single thread model

Single Thread Formation model

2.3 Model material properties

The bending of the thread remnant resulted in significant amount of plastic strain. The greatest strain occurs on the non-wearing side of the thread, which is in compression due to bending. The tensile strain occurs on the wearing side of the thread.

The ACME nut is made from a centrifugally cast Aluminum nickel bronze which was heat-treated. There were no full stress strain curves available for this material. Tensile and compression specimens were extracted from actual ACME nuts and run to generate full stress strain curves. The data for the 10 tension and 8 compression samples were averaged using the method described in MIL-HDBK-5H, page 9-74. The testing is documented in report LR-15955 “Alaska Airlines ASA261 Room Temperature Compressive- Tensile test for Gimbal nut”. The resulting data is shown in Tables 2.1 and 2.2. The engineering stress and strain data was converted to true stress and natural log of plastic strain using equations from the Abaqus users manual.

tension from 10 samples averaged per mil hdbk 5

engineering strain in/in	engineering stress psi	TRUE stress psi	Eln plast strain in/in
0	0	0	0.0000
0.0030	48000	48144	0.0000
0.0035	54870	55064	0.0001
0.0037	56560	56771	0.0002
0.0041	58550	58788	0.0004
0.0044	60210	60473	0.0006
0.0049	62450	62756	0.0010
0.0061	66040	66445	0.0020
0.0084	70380	70971	0.0039
0.0128	76310	77284	0.0079
0.0203	84120	85824	0.0147
0.0359	95180	98602	0.0292
0.0666	106240	113320	0.0574
0.0970	111580	122400	0.0849
0.1010	112040	123356	0.0885
0.1040	112450	124148	0.0912
0.1071	112830	124909	0.0939
0.1171	113770	127094	0.1028
0.1272	114600	129173	0.1116
0.1312	114920	129995	0.1151

Table 2.1 ACME nut tension test results

Single Thread Formation model

2.3 Model material properties (continued)

compression from 8 samples averaged per mil hdbk 5

engineering strain in/in	engineering stress psi	TRUE stress psi	Eln plast strain in/in
0	0	0	0.0000
-0.0025	-40000	-39900	0.0000
-0.0028	-43400	-43278	-0.0001
-0.0030	-45238	-45101	-0.0002
-0.0034	-48513	-48346	-0.0004
-0.0038	-51650	-51452	-0.0006
-0.0045	-55463	-55215	-0.0010
-0.0059	-62075	-61710	-0.0020
-0.0083	-68325	-67760	-0.0040
-0.0128	-76400	-75424	-0.0080
-0.0204	-86700	-84930	-0.0149
-0.0364	-102800	-99056	-0.0296
-0.0678	-124075	-115668	-0.0583
-0.0988	-140163	-126320	-0.0863
-0.1297	-154425	-134404	-0.1135
-0.1605	-168050	-141077	-0.1400
-0.1913	-180838	-146243	-0.1659
-0.2015	-184150	-147042	-0.1744
-0.2117	-186913	-147346	-0.1828

Table 2.2 ACME nut compression test results

Single Thread Formation model

2.3 Model material properties (continued)

The elements were divided into two groups. Most of the elements had the tensile properties applied. A section, which is in compression when the thread is loaded in bending, had the compressive properties applied. A plot of the two areas for material properties is shown in Figure 2.4.

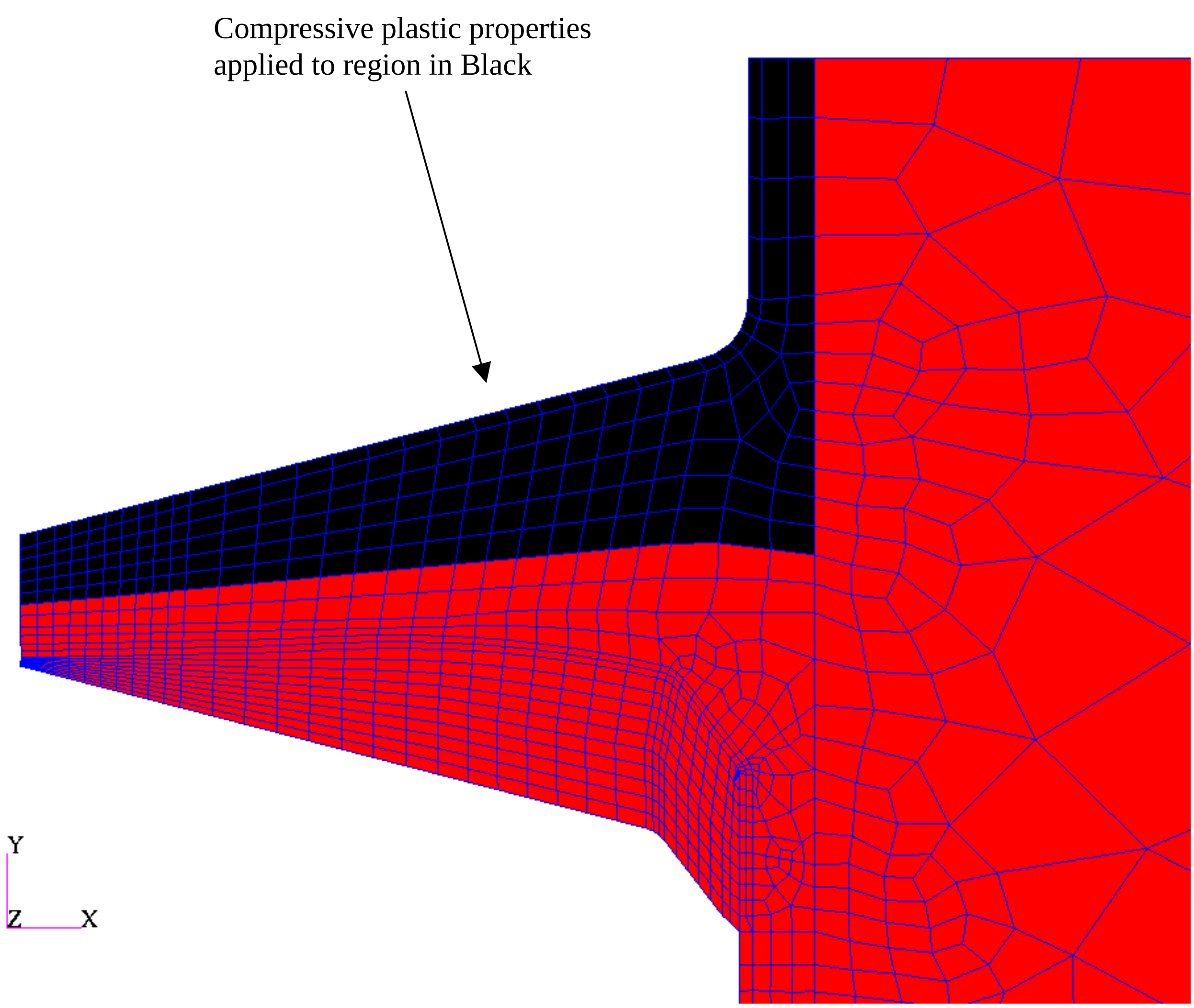

Figure 2.4 material properties on the single thread model

Single Thread Formation model

2.4 Model results

The deformed shape after the load – unload – remove procedure was completed for all 10 rows of wear material that was removed is shown in Figure 2.5. The summary of the step-by-step process is shown in Table 2.3. The applied load is the total load as if it were applied over one full-modeled thread. The residual plastic strain with no load applied to the thread is shown in Figure 2.6. The 0.105 inches of wear was determined as the limiting case for strength because the maximum tensile plastic strain of 0.113 was just below the maximum of 0.115 from the tensile test (Table 2.1)

Table 2.3 Summary of process from 0.080 to 0.105 inches wear

Step	Screw displacement from 0.080 wear (inches)	Tension Plastic Strain (in/in)	Compressive Plastic Strain (in/in)	applied pressure (ksi)	applied load (pounds)
1	0.00237	0.018	0.026	49.5	8709
2	0.00474	0.030	0.040	52.5	9193
3	0.00711	0.041	0.052	53.2	9274
4	0.00948	0.052	0.067	52.5	9117
5	0.01185	0.061	0.083	50.9	8805
6	0.01422	0.072	0.100	48.7	8391
7	0.01659	0.083	0.114	45.9	7908
8	0.01896	0.093	0.130	42.9	7385
9	0.02133	0.102	0.146	39.9	6867
10	0.0237	0.113	0.160	36.8	6333

Single Thread Formation model

2.4 Model results (continued)

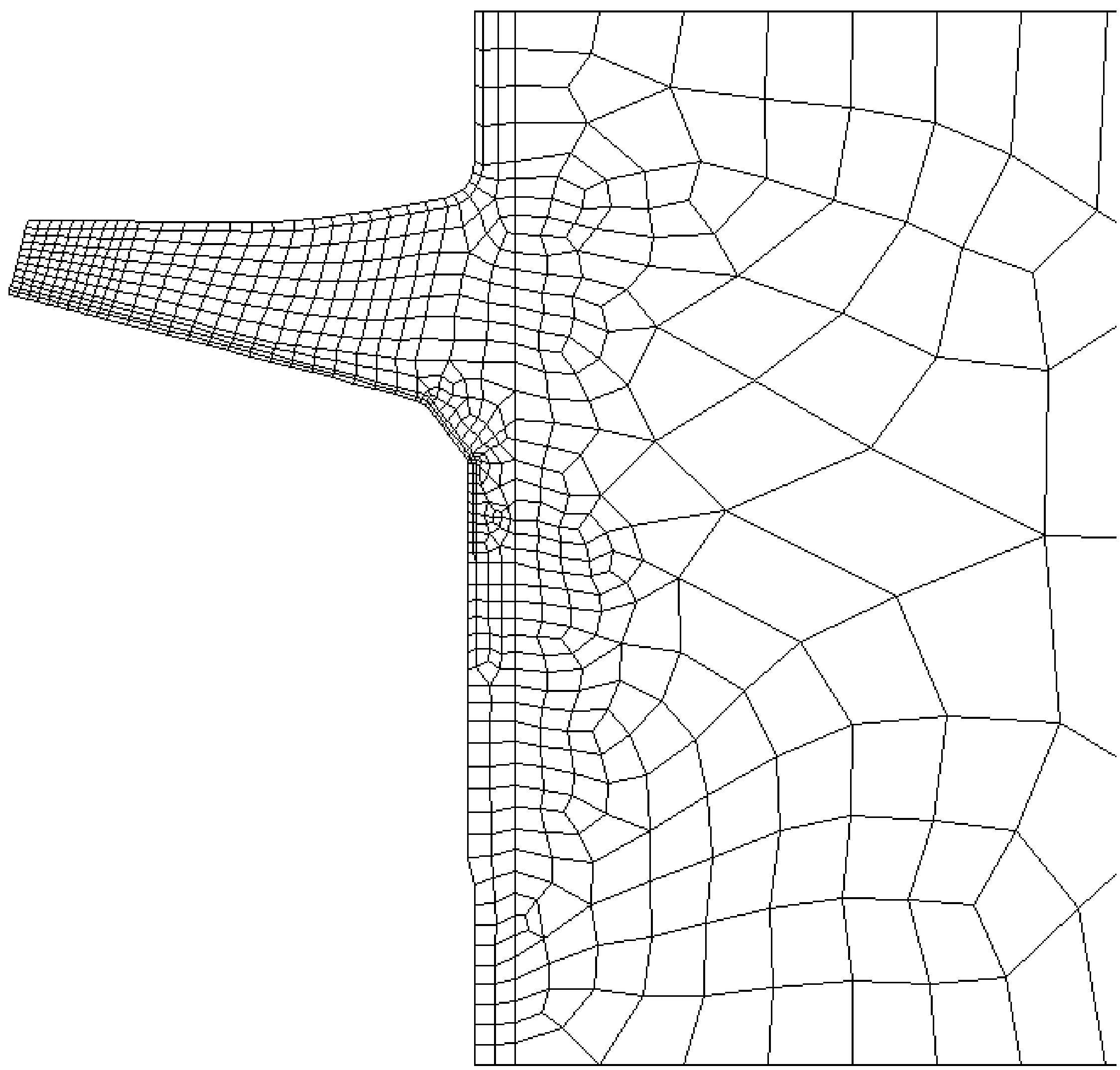

Figure 2.5 Deformed shape of ACME nut thread at .105 inches wear

Single Thread Formation model

2.4 Model results (continued)

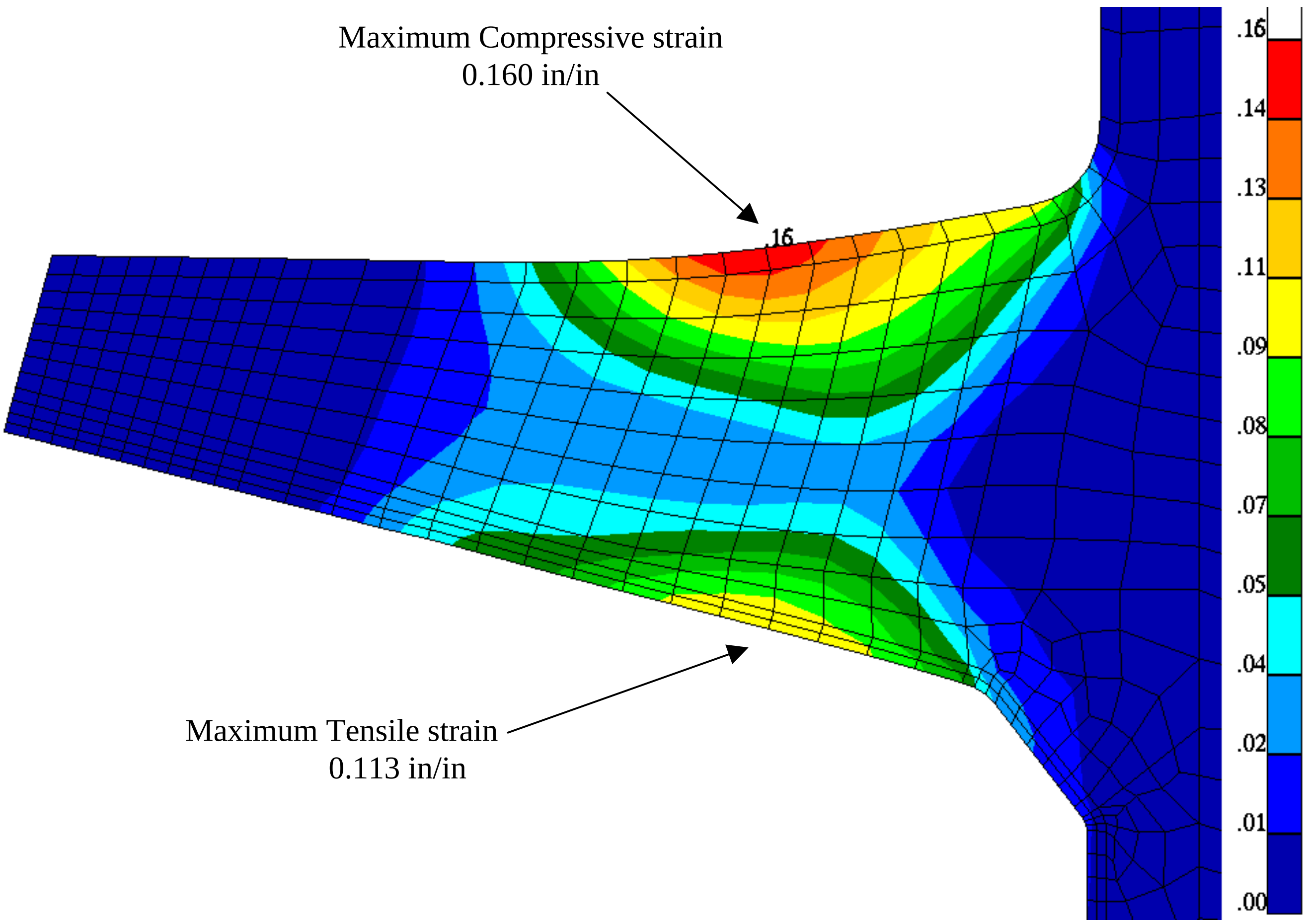

Figure 2.6 Equivalent Plastic Strain for ACME nut thread at .105 inches wear

Single Thread Formation model

2.4 Model results (continued)

In terms of normal operating conditions, the load indicated in Table 2.3 is misleading because it represents the load needed to displace the modeled thread over the full step of wear. The resultant load on the thread is significantly higher than that normally encountered in service. This indicates that the displacement of each thread occurs as a function of time as opposed to individual loading events. The details of the actual mechanism involve several different parameters (individual flight loads, dynamic load distribution along the thread, localized material behavior, actual wear rate, etc.) and is beyond the scope of this analysis. On an individual flight hour, however, the amount of deflection is very small. For example for a range of wear rates:

Low Wear rate =	0.001 inch per 1000 flt hrs
Wear from 0.080 to 0.085 inches wear =	0.005 inches
Flight hrs to wear from 0.080 to 0.085 = .005/0.001 x 1000 =	5000 flt hrs
Plastic thread tip displacement from 0.080 to 0.085 =	0.0047 inches
Plastic thread tip displacement per flight hrs = .0047/5000 =	9.4×10^{-7} inches per flight hrs

High Wear rate =	0.010 inch per 1000 flt hrs
Wear from 0.080 to 0.085 inches wear =	0.025 inches
Flight hrs to wear from 0.080 to 0.085 = .005/0.010 x 1000 =	500 flights
Plastic thread tip displacement from 0.080 to 0.085 =	0.0047 inches
Plastic thread tip displacement per flight hrs= .0047/500 =	9.4×10^{-6} inches per flight hrs

The single thread model was run for various loads to determine how the permanent set varies with load. A plot of the permanent set versus load is shown in Figure 2.6. The resulting plot shows the plastic thread displacement for high and low wear rates. The load required every flight hour to cause the thread remnant is shown in red in Figure 2.6. The model indicates that each thread would need 2500 to 3500 pounds of load applied every flight hour at the 0.080 inches wear. The load required would be reduced if it were applied over less than 360 degrees of thread.

Single Thread Formation model

2.4 Model results (continued)

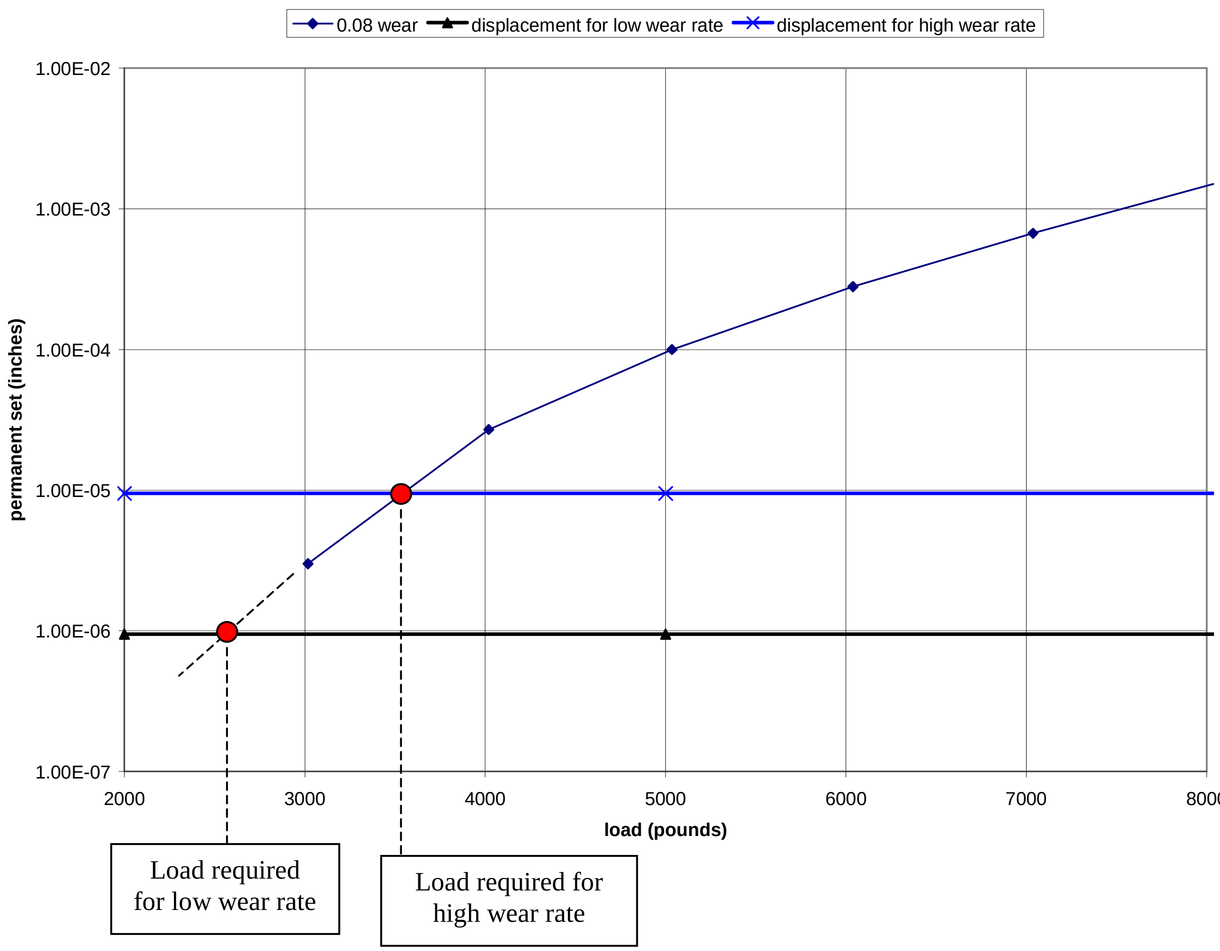

Figure 2.7 ACME nut thread tip permanent displacement versus load

3.0 Full Assembly Model

The resulting geometry from the single thread formation model was next integrated into a complete jackscrew assembly model. The full ACME nut has 32 threads over an 8-inch length.

Preliminary models with simplified geometry indicated that if a model was built with all threads identical, the load concentrates on the bottom few threads. In the actual nut, if the screw was precisely perfect and all of the wear occurred at a single temperature, the threads would wear so that all of the threads would carry the same load at the wearing load. As the load increases above the wearing load, the stretching of the nut combined with the compressing of the screw results in the load shifting to the bottom few threads. By not adjusting the nut thread geometry to have uniform loading on the threads at the wearing load, the model tends to concentrate the load to fewer threads, which is conservative for strength evaluations. This assembly model has all of the threads identical.

3.1 model geometry

The overall assembly model is shown in Figures 3.1 to 3.2. The assembly includes the entire load path between the upper bearing race to the lower tip of the jackscrew assembly. The various components in the assembly except for the ACME nut are shown in Figure 3.1. The ACME nut and screw are shown in Figure 3.2. The nut thread geometry is identical to the single thread formation model after it was worn to 0.105 inches wear. In addition to having the exact geometry of the thread formation model, the plastic strains from the formation were also included. Only the lower 4 threads use the exact thread formation models. All of the other threads have the same outside geometry, but the mesh density was reduced to reduce run times to an acceptable level. This should not affect load distribution or fracture load because at typical flight loads all displacements are elastic. For the limit and ultimate loads, the load induced yielding only occurred on the first three threads.

The material properties for each of the components except the ACME nut are the same as used for the wear band analysis reported in MDC01K9053, “HS Jackscrew Torque Tube Wear Band Strength Analysis”. The ACME nut material properties are identical to those used in the single thread formation model.

Full Assembly Model

3.1 model geometry (continued)

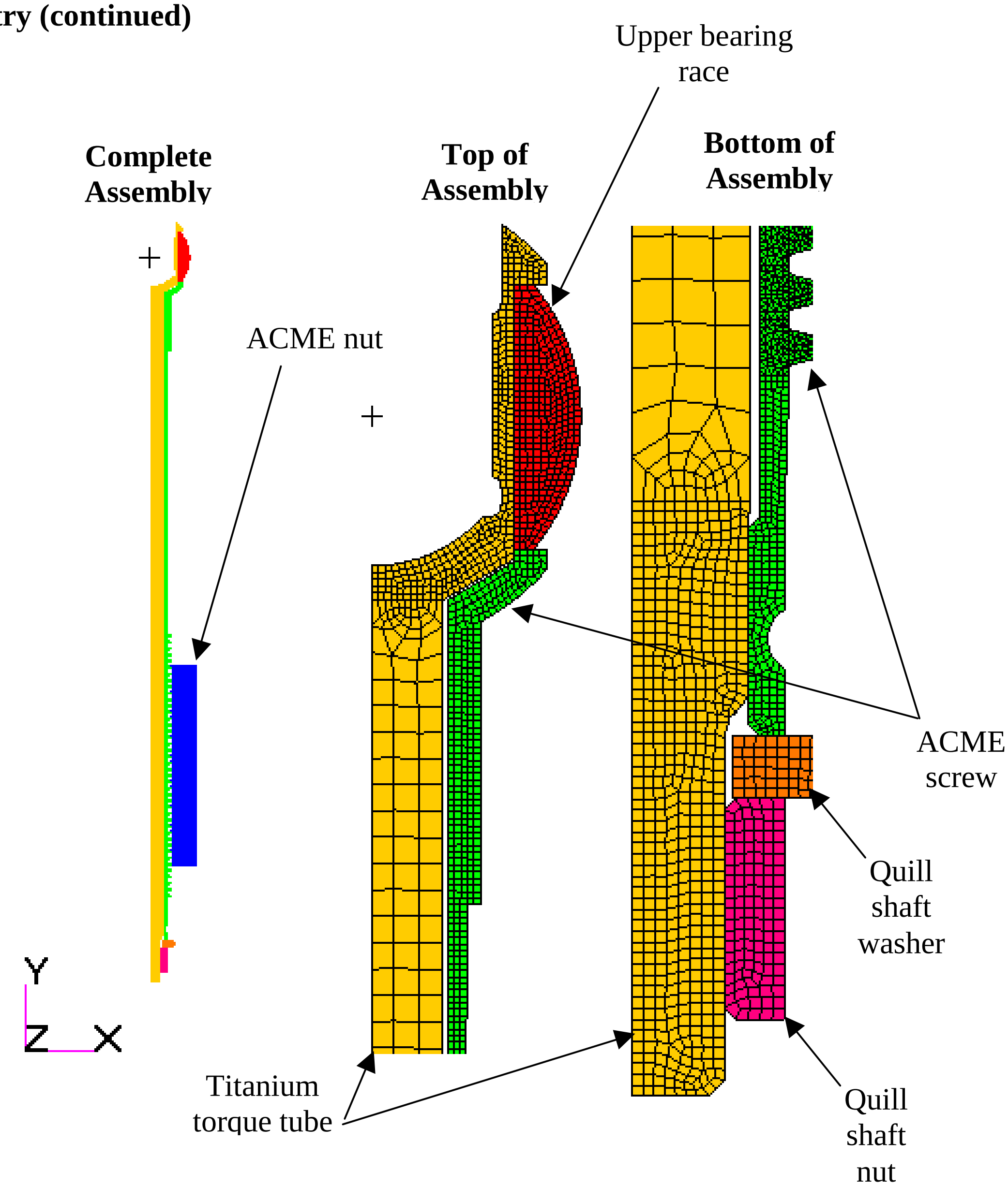

Figure 3.1 assembly model

Full Assembly Model

3.1 model geometry (continued)

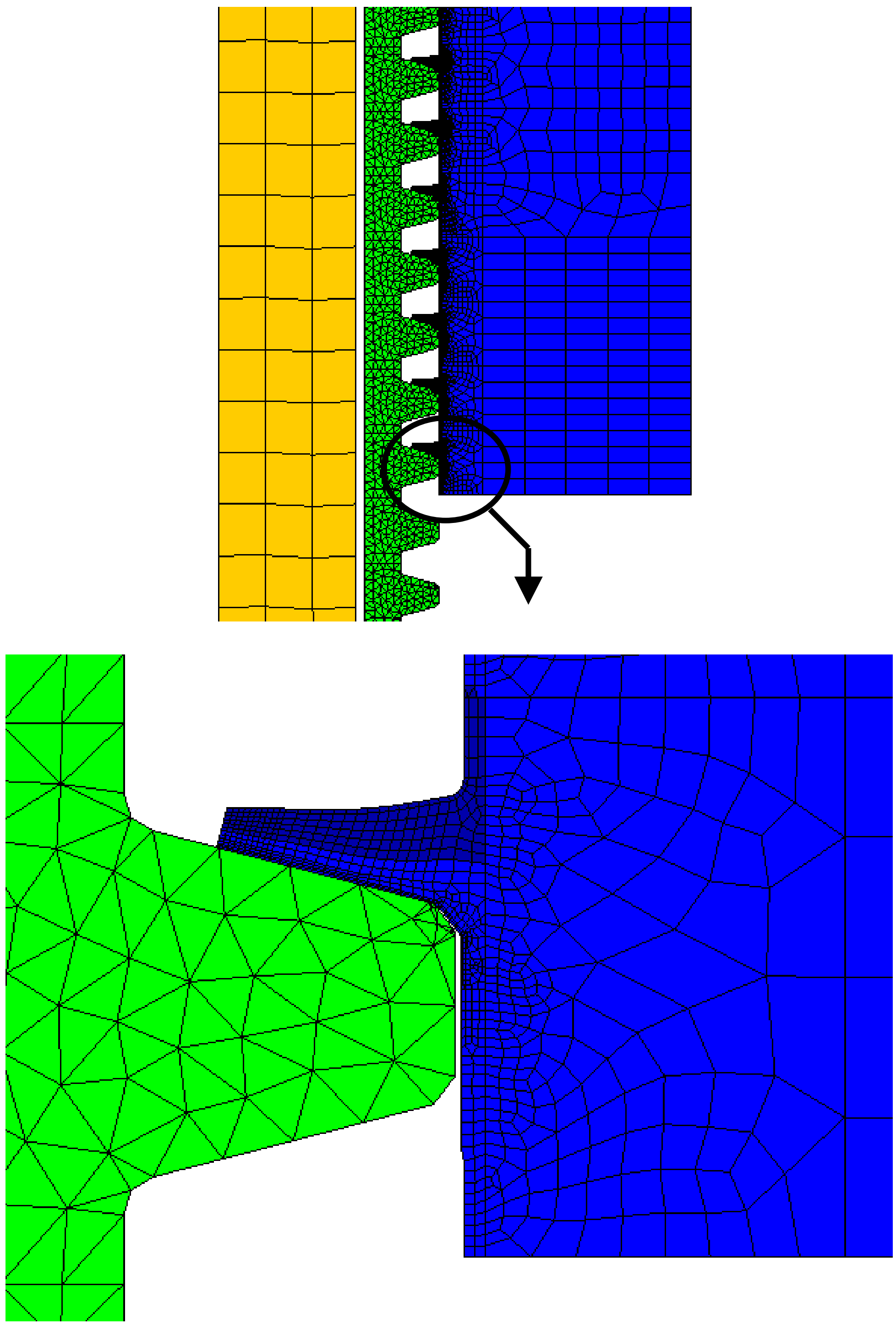

Figure 3.2 assembly model

Full Assembly Model

3.2 Model Boundary conditions

The boundary conditions on the model are shown in Figures 3.3 through 3.5. The model was constrained vertically at the center of the upper bearing race, as shown in Figure 3.3. All vertical interfaces between parts were modeled with contact. The torque tube nut preloads the total assembly. This preload was simulated using a preload tool in the Abaqus program. A cross section within the torque tube was defined as shown in Figure 3.4. This section is defined in Abaqus as a preload section, which allows the preload force to be applied across that section. Once the preload force has been applied, the relative displacement across the preload section is held constant, which results in the same behavior as tightening the torque tube nut to induce the preload.

The external load was applied along the outer edge of the ACME nut, as shown in Figure 3.5. The model was assembled and loaded in the following steps:

1. The torque tube preload of 4549 pounds was applied. The part initial temperature of the assembly was 70 degrees F. All contact surfaces between components were active except for the ACME screw to nut thread contact was temporarily removed. The ACME nut was held fixed until it was added to the assembly later.
2. The torque tube preload was converted from a force load to an enforced displacement so the assembly would behave correctly.
3. The contact between the ACME screw and nut is added. The ACME nut is translated down to put a small external load on the nut.
4. The fixed translation on the ACME nut is removed and 1600 pounds total load is applied. The 1600 pounds is the nominal 1g load for ground operations.
5. The external load was increased to 5000 pounds and the temperature was reduced to 7.3 degrees F. This represents a typical flight load and the temperature at the ultimate load condition.
6. The external load was increased to 10,000 pounds
7. The external load was increased to limit load of 38,000 pounds
8. The load was increased to ultimate load of 57,000 pounds
9. The load was increased until the fracture criterion was met. A conservative criterion was set as any element equivalent plastic strain exceeded the ultimate plastic strain was fracture. The fracture load was slightly above 57,000 pounds.

The model was rerun with room temperature for all conditions so a comparison could be done.

Full Assembly Model

3.2 Model Boundary conditions (continued)

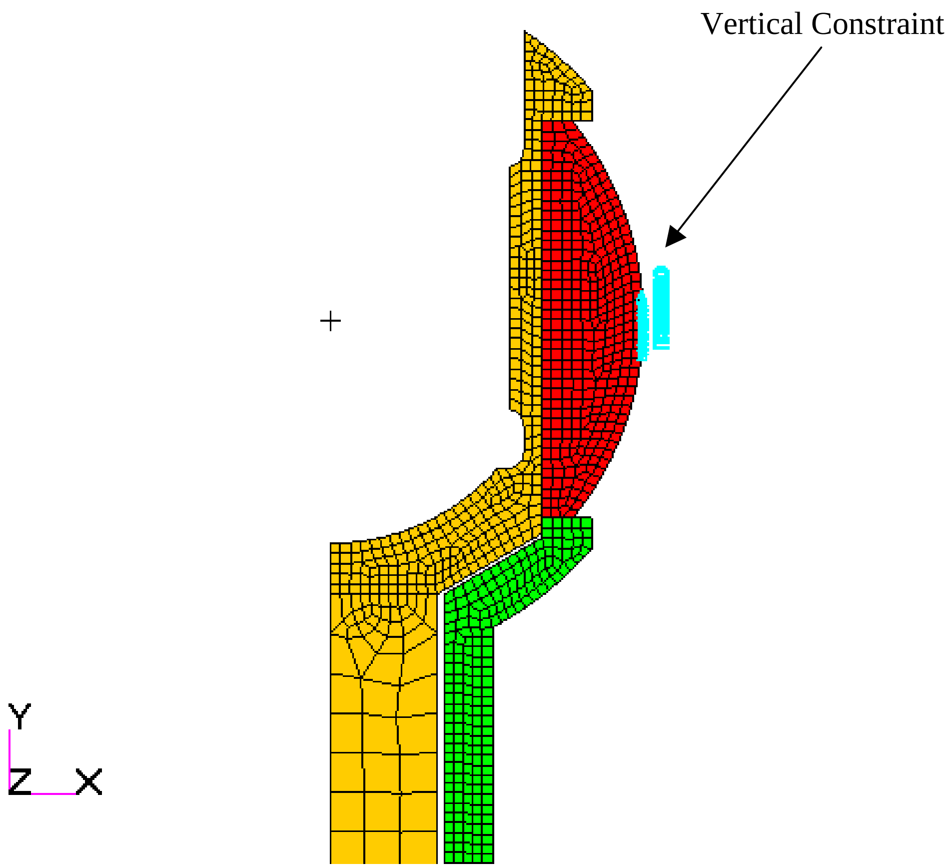

Figure 3.3 Boundary conditions on assembly model

Full Assembly Model
3.2 Model Boundary conditions (continued)

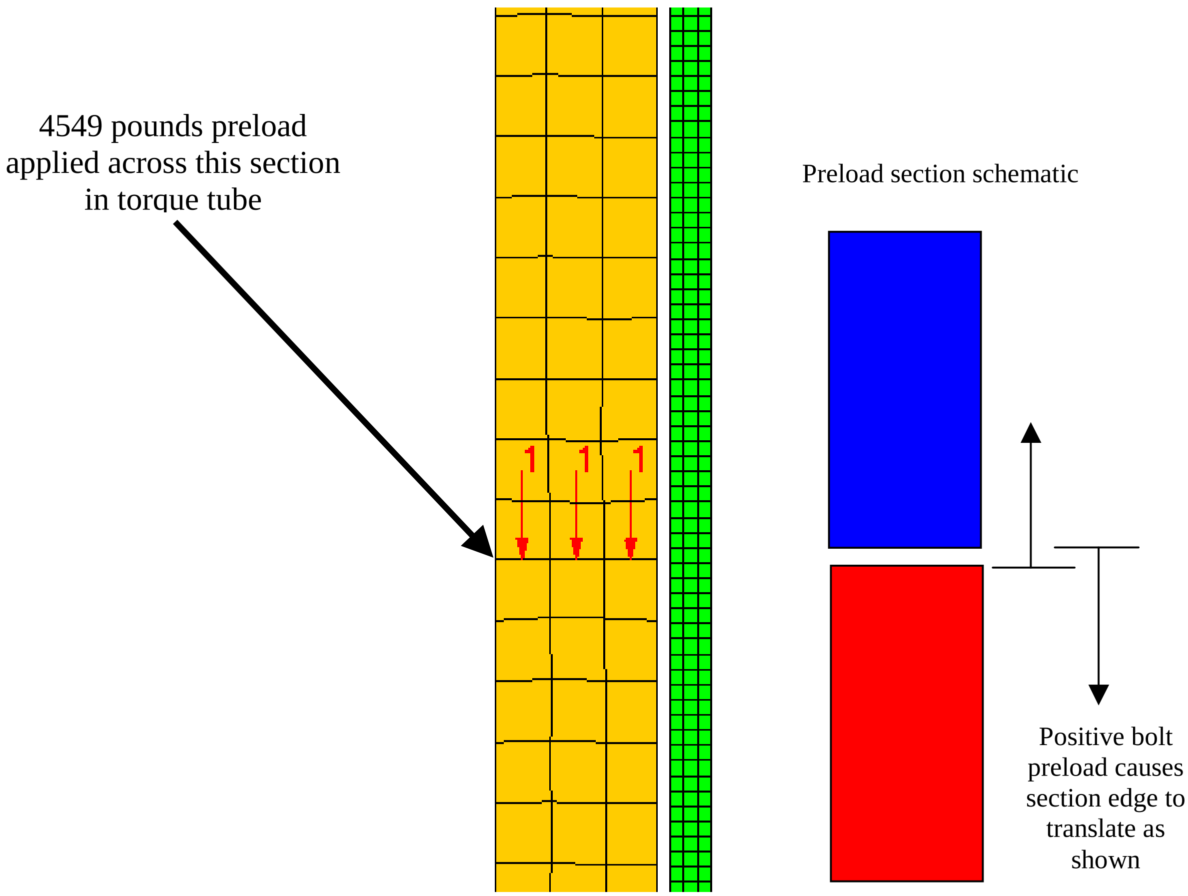

Figure 3.4 Boundary conditions on assembly model

Full Assembly Model

3.2 Model Boundary conditions (continued)

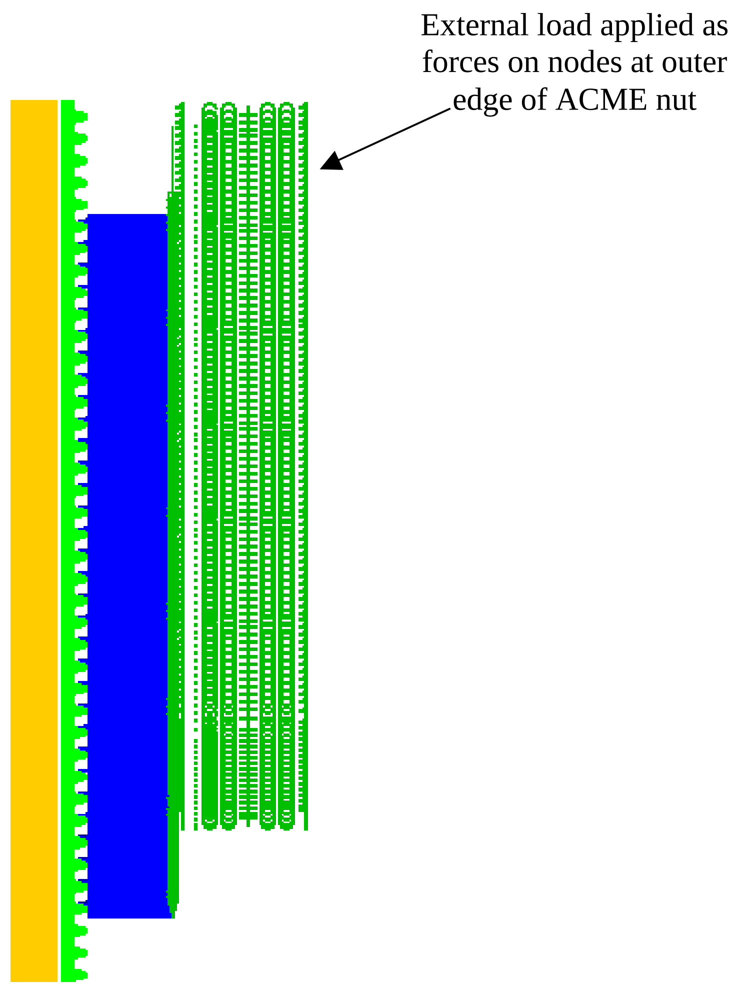

Figure 3.5 external load on ACME nut

Full Assembly Model

3.3 model results

The low temperature case was defined as the temperature at which the ultimate load case occurs. The altitude for the ultimate load case was 15,000 feet (Reference MDC J6258, "DC-9 basic flight loads", page 4-25,26). The temperature at that altitude for standard atmosphere is 5.54 degrees F (Reference Lockheed report 9000-A, page 101).

The assembly model is identical to the one used for the wear band analysis, which was documented in MDC01K9053, "HS Jackscrew Torque Tube Wear Band Strength Analysis". The only changes were the addition of the ACME screw threads and ACME nut. For assembly behavior, refer to the wear band report.

The contact pressure distribution between threads is shown in Figures 3.6 to 3.9 for various load conditions. The 1600-pound ground load case is shown in Figure 3.6. Only the bottom three threads were in contact for this load case. The contact pressure is shown over the thread profile in Figure 3.7. The contact occurred only over $1/3^{rd}$ of the thread flank and the load peaked at the tip of the ACME screw thread, near the root of the ACME nut thread.

The contact pressure distribution for typical flight load of 5000 pounds at low temperature is shown in Figure 3.8. The thread numbering was done starting with the bottom thread and increasing upwards. The bottom ten threads are shown along with the top 2 threads. The pressure profile is very uniform in shape, with a small variation between the bottom and top threads.

The variation of the maximum contact pressure for each thread is shown in Figure 3.9. The plot includes all load cases run with this model. Figure 3.9 shows that:

- Except for the 1600 pound and 5000 pound room temperature load cases, all of the threads are in contact for all load cases
- The drop in temperature causes the threads at the top of the nut to pick up some load.
- The peak load always occurs on the first (bottom) thread. The only exception to this is the 5000 pound cold condition, which has a maximum load on the last (top) thread.
- For typical flight loads (at or below 10,000 pounds) the first 10 threads carry most of the load for room temperature conditions, and both first and last 10 threads carry most of the load for the cold temperature condition.

Full Assembly Model

3.3 model results (continued)

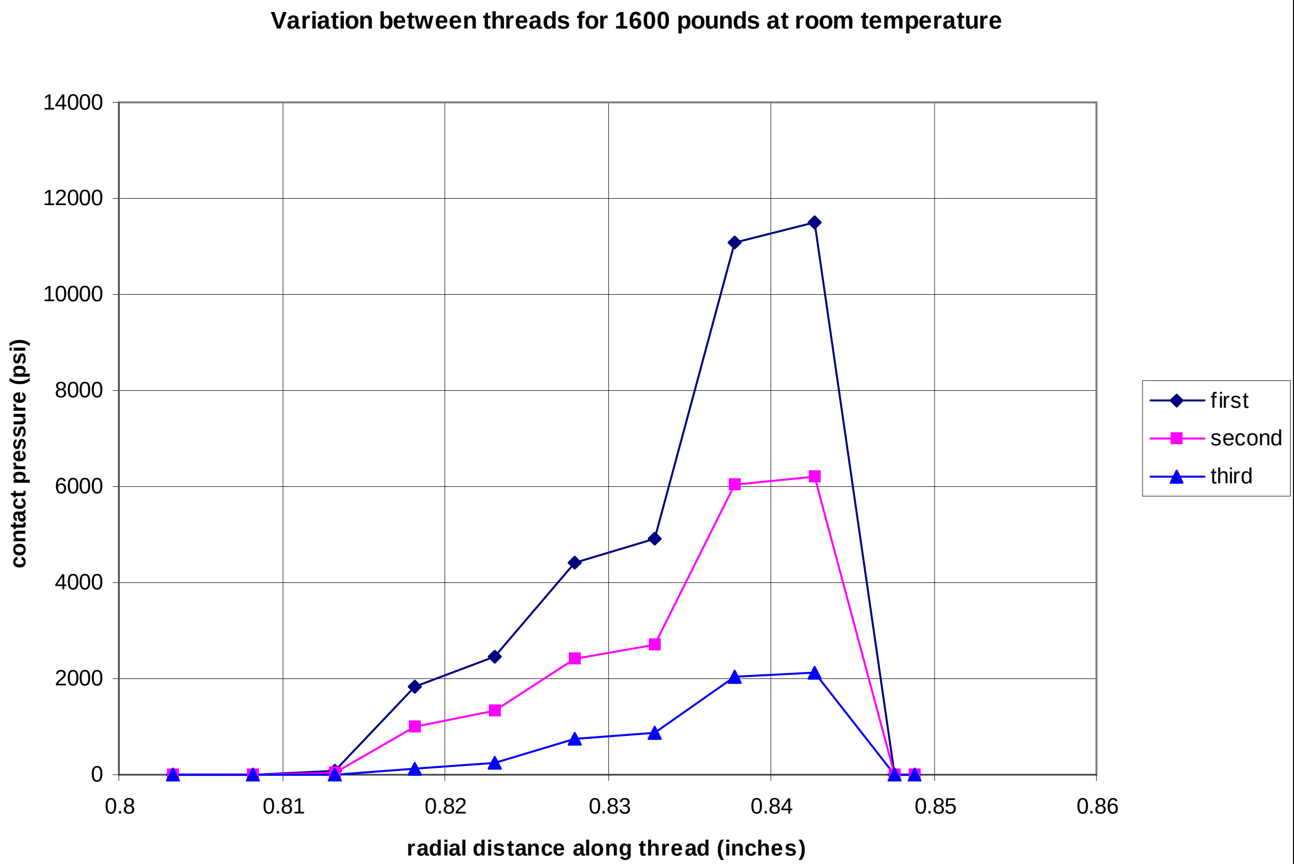

Figure 3.6 contact pressure distribution for 1600 pound load case

Full Assembly Model

3.3 model results (continued)

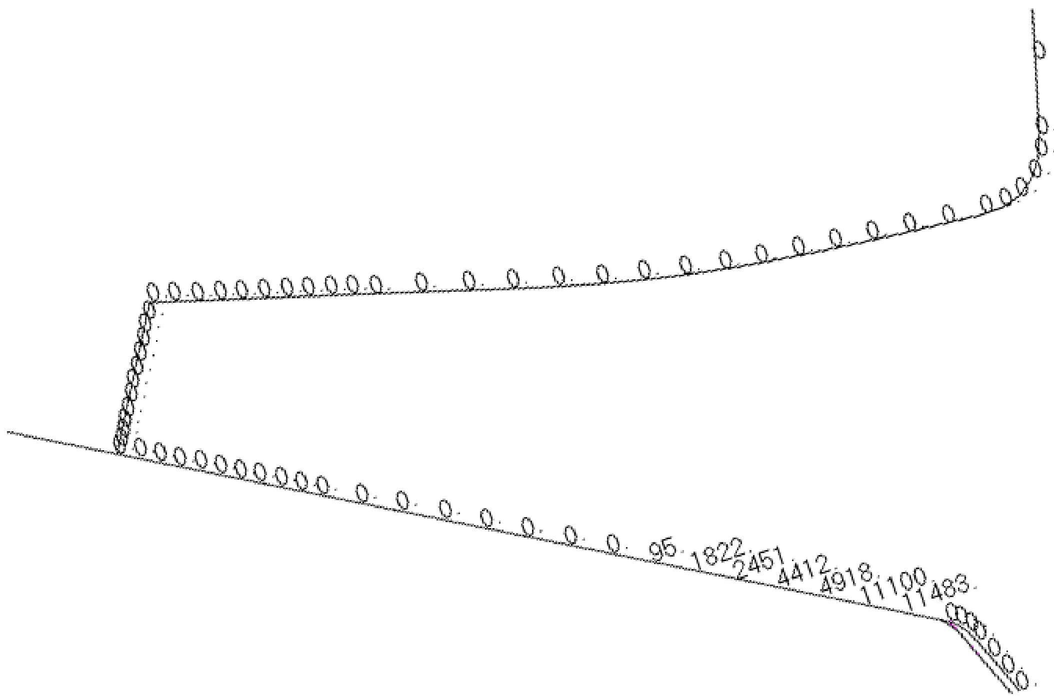

Figure 3.7 contact pressure on bottom thread for 1600 pound load

Full Assembly Model

3.3 model results (continued)

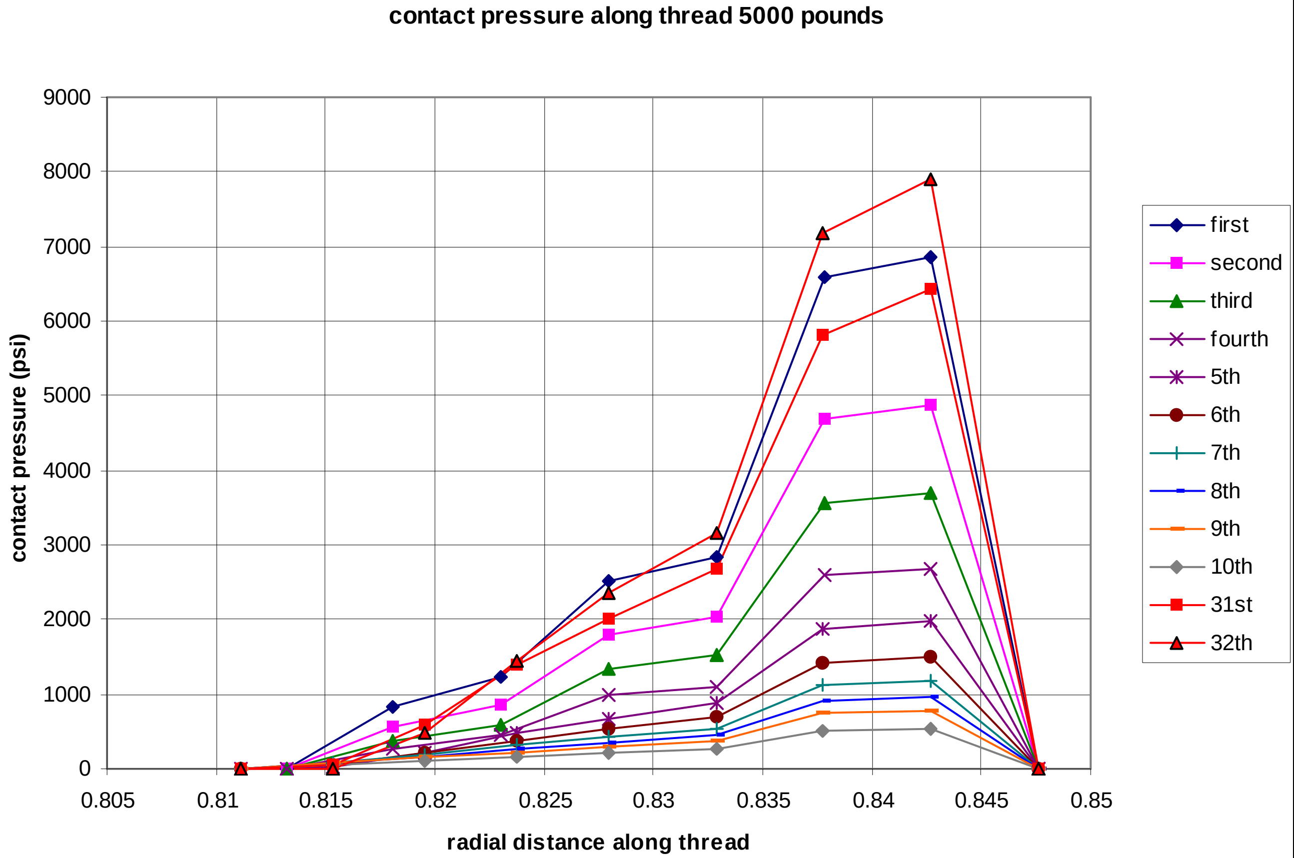

Figure 3.8 contact pressure on bottom thread for 5000 pound load at low temperature

Full Assembly Model

3.3 model results (continued)

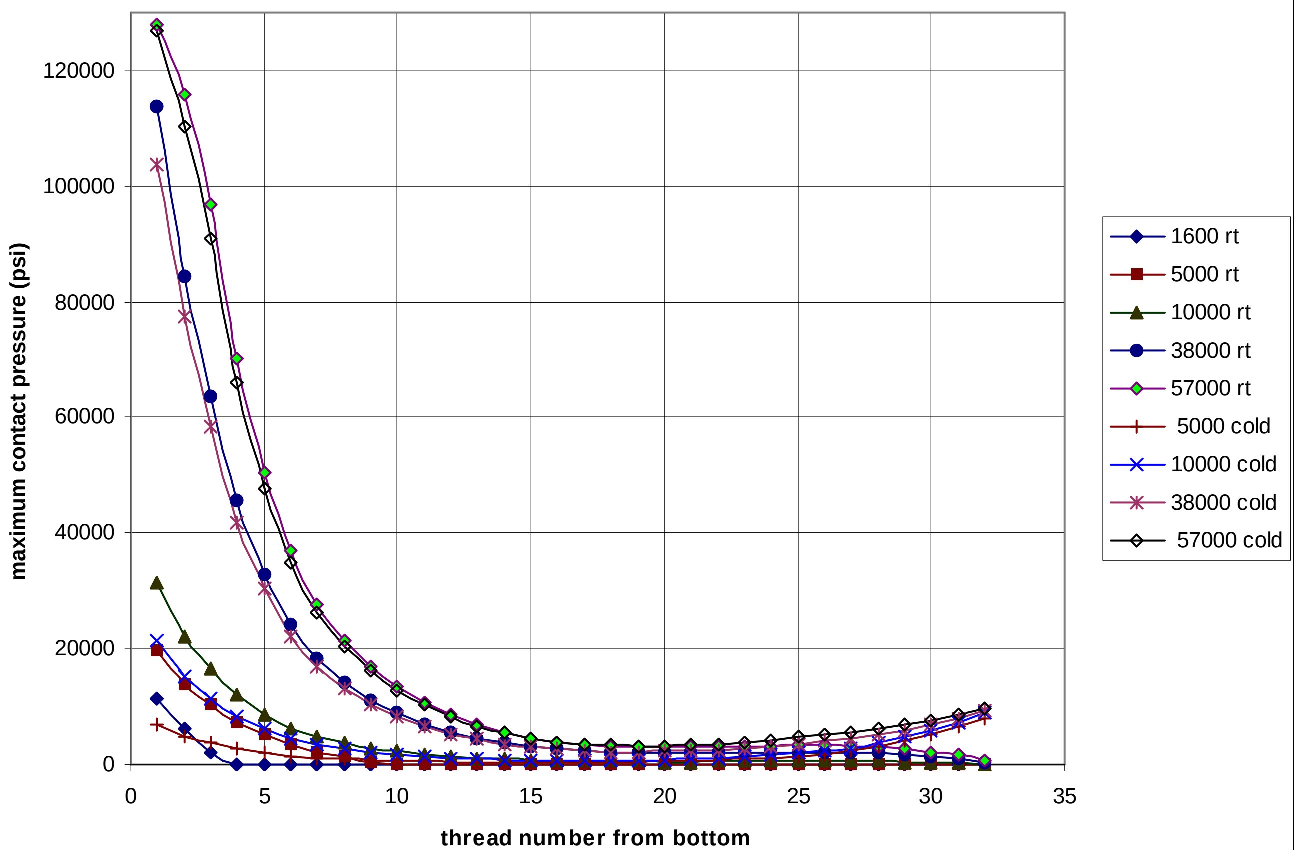

Figure 3.9 maximum contact pressure for each thread for various load cases

Full Assembly Model

3.3 model results (continued)

The contact pressure was converted to fraction of load carried by each thread. Because the thread contact load pressure distribution was very consistent, the total load carried by each thread was assumed to be related to the maximum pressure on each thread. So by dividing the maximum pressure by the sum of maximum pressures, the load distribution could be estimated. The load distribution estimate is shown in Figure 3.10. Figure 3.10 shows that:

- As the load level increases, the maximum percentage of load carried by any thread decreases
- The low temperature load cases have much lower maximum percentage of load carried by any single thread than the room temperature cases.
- At the typical flight load of 5000 pounds at the flight temperature, the first and last threads carry only 0.10 and 0.12 fraction of the load. This calculates out to 500 pounds on the bottom thread and 600 pounds on the top thread. Even if the typical flight load occurred at room temperature, the maximum load on the first thread is calculated to be 1550 pounds. These loads are well below the level required to plastically deform a nut thread.

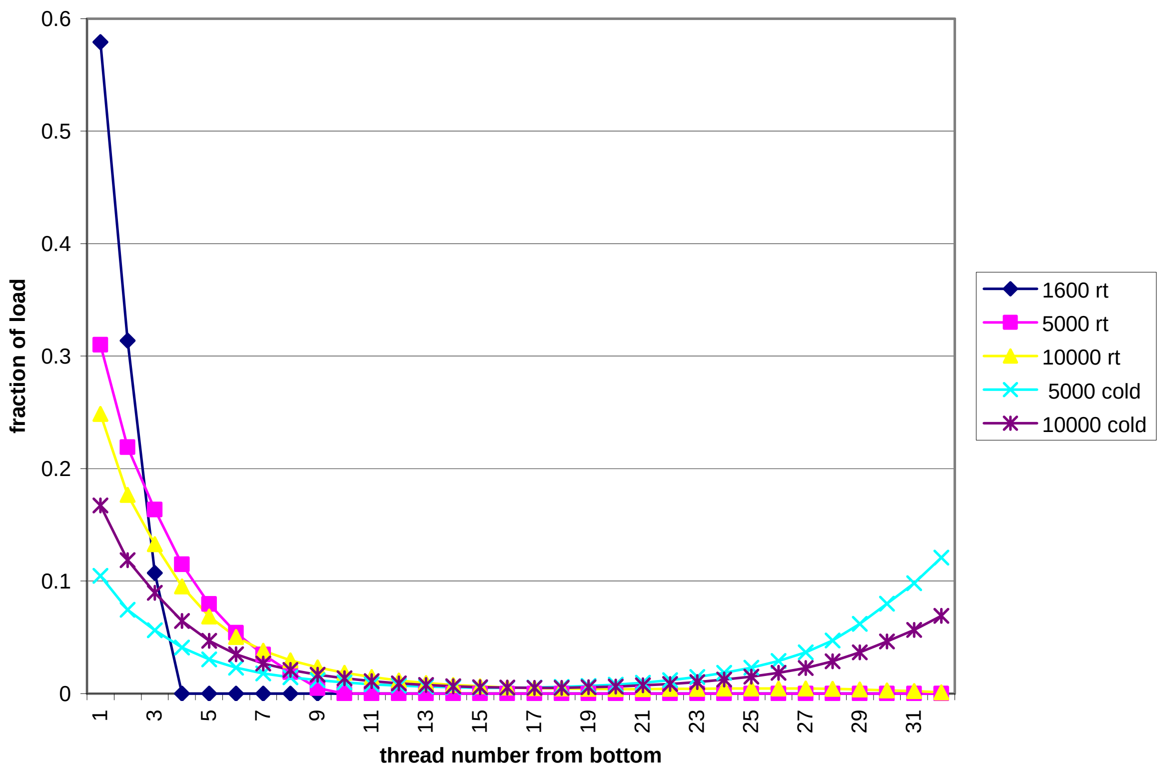

Figure 3.10 fraction of load carried by each thread for various load cases

Full Assembly Model

3.3 model results (continued)

The equivalent plastic strain plot for the bottom thread at the 1600 pound load case is shown in Figure 3.11. The strain is from the thread formation model. No plastic deformation occurs at the 10,000-pound maximum normal operating flight load condition. Some plastic deformation does occur at the limit load condition of 38,000 pounds. A difference plot, which just shows the delta plastic strain that occurred after thread formation, is shown in Figure 3.12.

The model was run until fracture was indicated at both the room and cold temperature conditions. The room temperature model indicated fracture at a lower load, which was just above the 57000 pounds ultimate load. The equivalent plastic strain plot for the room temperature ultimate load case is shown in Figure 3.13. The criteria for defining fracture was if the equivalent plastic strain exceeded the maximum determined from the tensile test data, which is 0.115 in tension and 0.183 in compression.

Accumulative strain due to the bending during the formation process occurs at a different location than when the maximum jackscrew load is applied to obtain fracture. The fracture mode is shear due to the acme nut thread loaded more toward the root. This is consistent with the thread remnant recovered from ASA 261.

Full Assembly Model

3.3 model results (continued)

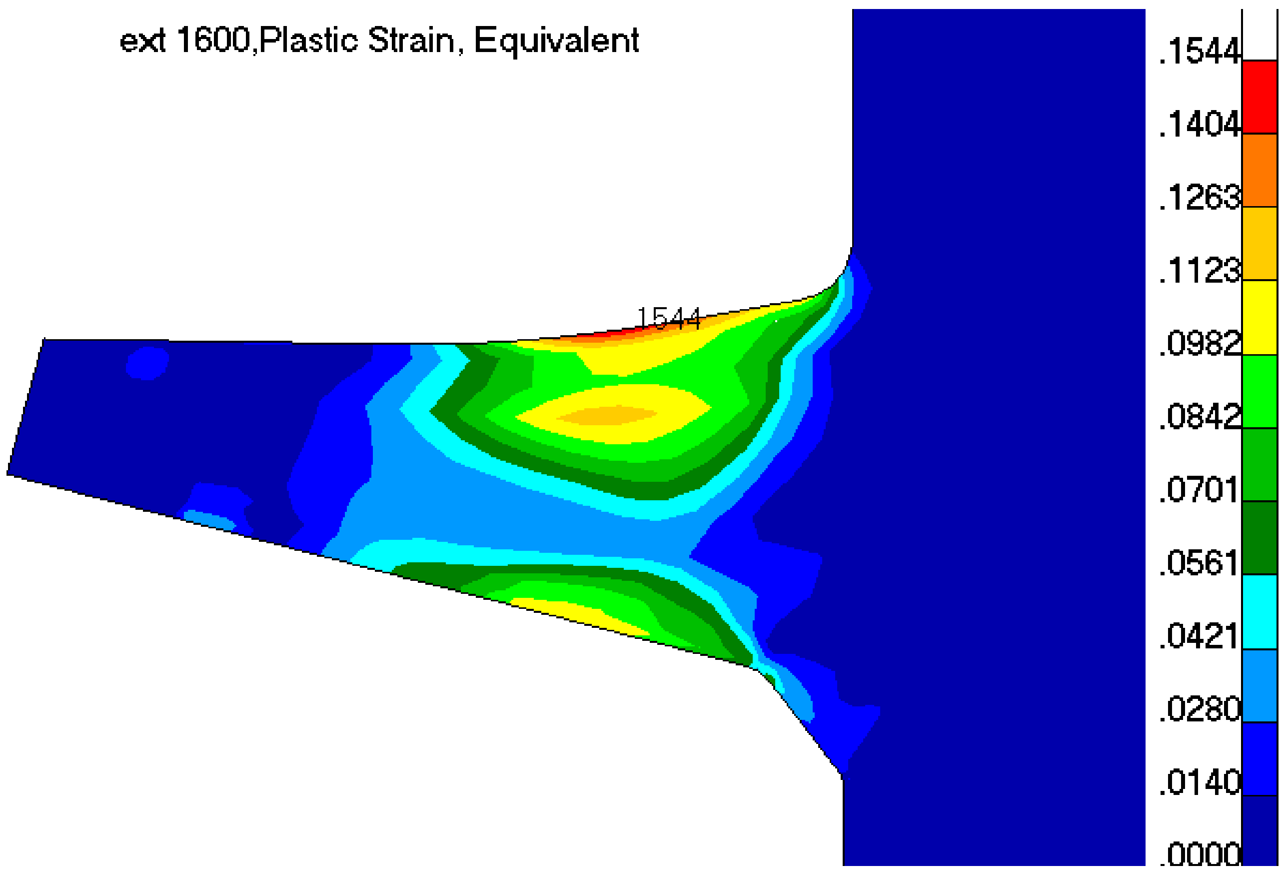

Figure 3.11 equivalent plastic strain for bottom thread at 1600 pound load

Full Assembly Model

3.3 model results (continued)

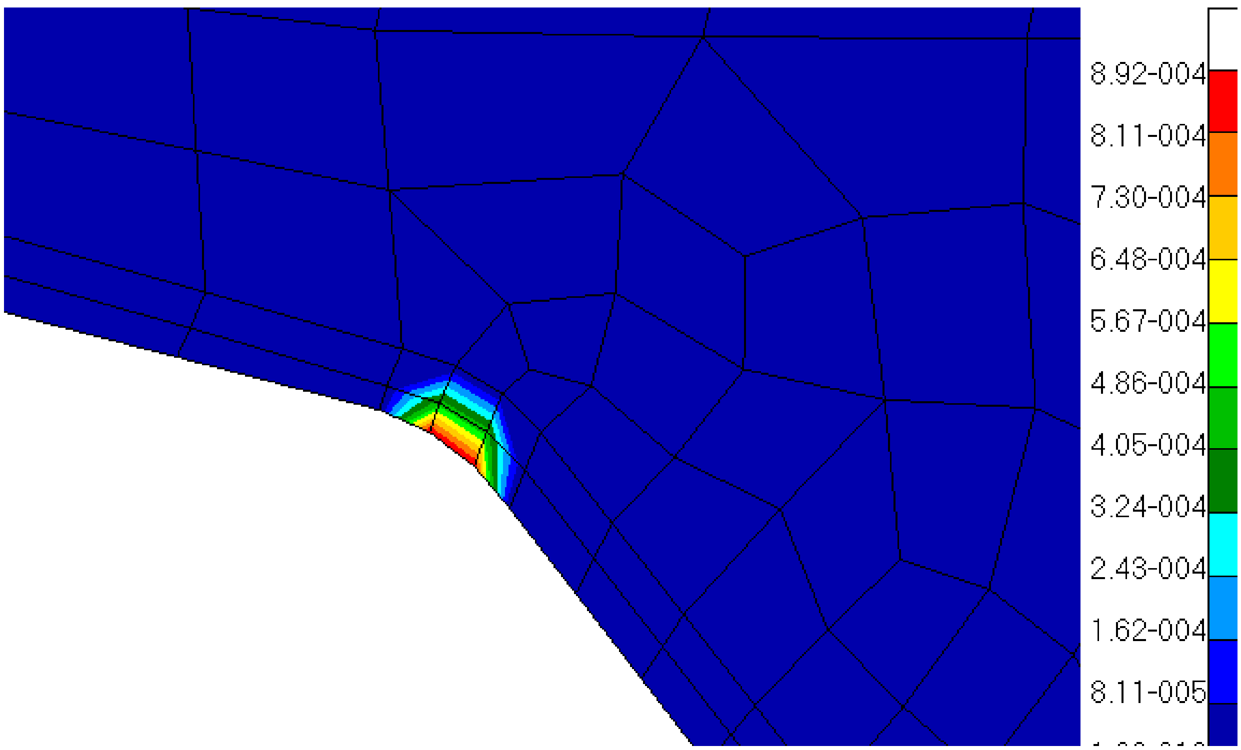

Figure 3.12 change in equivalent plastic strain for bottom thread at 38,000 pound load

Full Assembly Model

3.3 model results (continued)

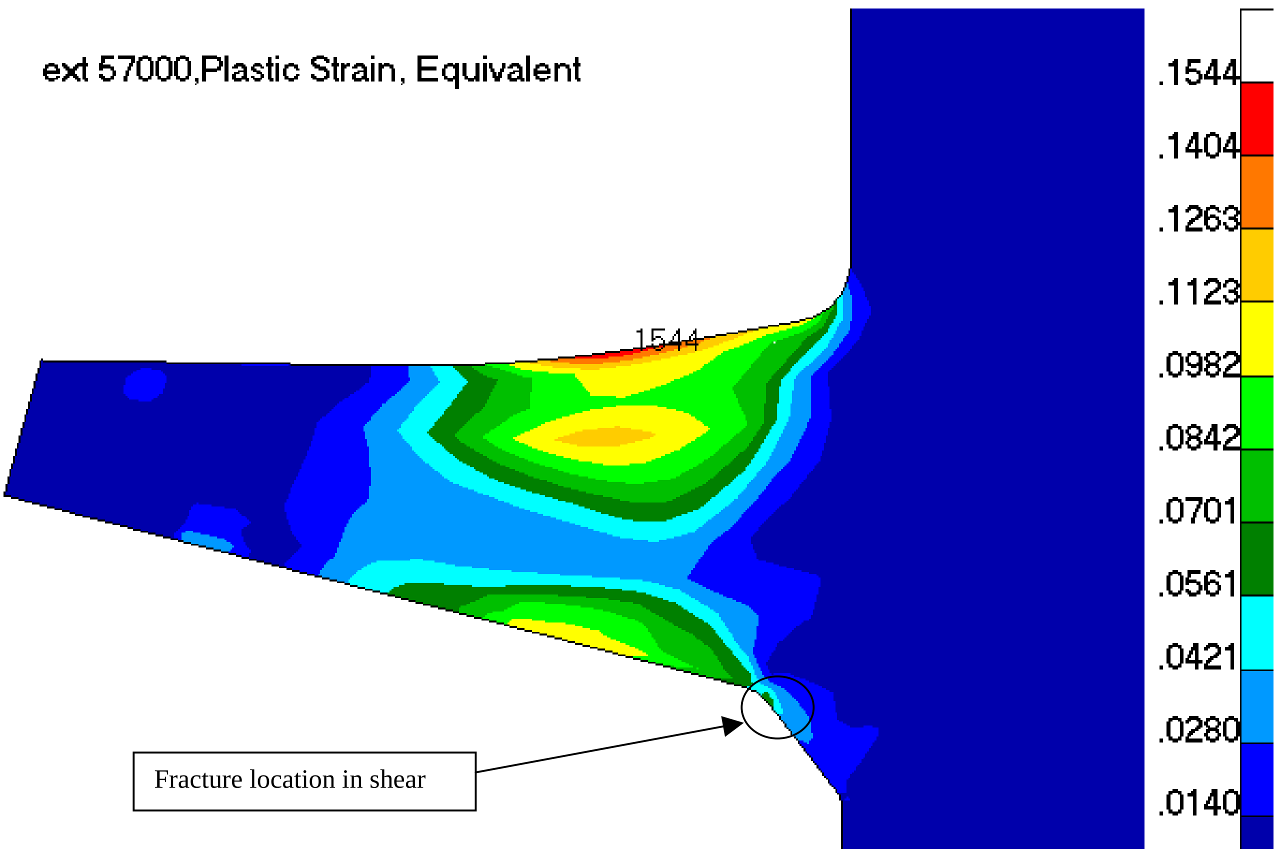

Figure 3.13 equivalent plastic strain for bottom thread at 57,000-pound load for room temperature

4.0 Summary

Based on the physical evidence of the thread remnant shape, during the wear process, the ACME nut thread started to plastically deformed during the wearing process at approximately 0.08 inches of wear. The full length of the non-wearing flank of the thread was intact, though the wear level was well past when the tip should have been worn away. The thread plastically deformed to prevent the tip from wearing.

The thread remnant non-wearing side was curved indicating that the thread must was subjected to bending. The single thread model results showed that in order to produce bending in the thread, the load was concentrated towards the tip of the ACME nut thread. The single thread model also indicated that each thread had to be subjected to a fairly large load in order to plastically deform it. For the wearing from 0.080 to 0.085 inches, the load required ranged from 2500 to 3500 pounds. The assembly model showed that at the typical flight load of 5000 pounds, the maximum load seen by any individual thread was only 1550 pounds. The assembly model also showed no plastic deformation until the load approached limit load, which is an extremely rare event. These results indicate that the thread plastic deformation could not of occurred as the result of loading events during normal flight conditions.

The caveat on the assembly model results is that all of the threads were modeled identical. The wearing process on the actual nut would adjust the profiles so the threads would have uniform load distribution at the wearing loads. Thus, the model indicates higher contact pressures and load distributed over fewer threads than the actual nut would.

The wear level of 0.105 inches was determined to be the maximum wear while maintaining ultimate load carrying capability. Nearly all of the accumulated strain was due to the thread remnant formation process. At a wear of 0.105 inches, the assembly model withstood the ultimate load of 57,000 pounds and still did not indicate that fracture would occur. The critical area during ultimate load was near the root of the thread and was not concurrent with the accumulative strain due to bending. Thus, the model indicated a shear mode of fracture.