



Improved Buttress Thread Machining for the Excalibur and Extended Range Guided Munitions

Raytheon – Tucson, AZ

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Buttress Thread Machining Technical Report Summary Final Report

**Raytheon Missile Systems Company
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14. ABSTRACT Raytheon requested the NCDMM to evaluate and optimize buttress thread machining. Raytheon's suppliers have had problems producing buttress threads that meet the specified tolerances. These suppliers have tried various types of manufacturing methods but are still unable to consistently produce quality buttress thread components for Raytheon. NCDMM was asked to do the following things: optimize machining of fine pitch Class III Buttress Threads for the Excalibur and ERGM components. Provide training to Raytheon personnel to adapt the newly optimized buttress thread machining technique to all Excalibur and ERGM components. &#61472;Assist Raytheon in evaluating and optimizing the buttress thread measuring techniques and instruments/gages.					
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1.0 Introduction

1.1 Description and Purpose

The NCDMM was assigned a task by Raytheon, (Tucson, AZ) to evaluate and optimize machining of fine pitch (20 TPI) 7°/45° Class III internal and external buttress threads for their Excalibur and the Extended Range Guided Munitions (ERGM) components.

1.2 Task Objectives

Under this assignment, the NCDMM was charged with completing the following objectives:

- Optimize machining of fine pitch (20 TPI) 7°/45° Class III Buttress Threads for the Excalibur and ERGM components.
- Provide training to Raytheon personnel to adapt the newly optimized buttress thread machining technique to all Excalibur and ERGM components.
- Assist Raytheon in evaluating and optimizing the buttress thread measuring techniques and instruments/gages.

2.0 Summary

Raytheon requested the NCDMM to evaluate and optimize buttress thread machining. Raytheon's suppliers have had problems producing buttress threads that meet the specified tolerances. These suppliers have tried various types of manufacturing methods, but are still unable to consistently produce quality buttress thread components for Raytheon.

The NCDMM specifically tested the machining parameters for fine pitch (20 threads per inch) internal and external buttress threads (7°/45° Class III). The material used in these tests was 3.5" diameter sections of 4340 Steel with a Rockwell hardness of up to C53. Eight pieces of the 4340 material was received for testing. Four of the eight pieces were solid and would be used for external threading, while the other four were hollow (2.985" internal diameter) and would be used for internal threading. Each set of four contained two pieces six inches in length and two pieces three inches in length. The pieces three inches in length were machined as tensile specimens that would be tested by Raytheon. The tensile test will check the overall strength of the Class III buttress threads machined by NCDMM. The pieces six inches in length were used for design of experiment (DOE) tests, where three different machine-cutting depths and three different machine speeds were selected as the control variables. The control variables were arranged so that a total of six experiments were performed for each DOE test.

3.0 Butress Thread Test Setup

Two DOE tests were used in the optimization and evaluation process of butress thread machining. One DOE was performed to evaluate the internal threading process while the other was performed to evaluate the external threading process. A Fryer Easy Turn lathe and a HAAS SL-20 lathe were used for the required machining. All operations described herein required the use of a coolant during the machining of the threads. Castrol Syntilo 9904 was the coolant used in both lathes during machining.

3.1 Butress Thread Tooling

Three special inserts were ordered to perform the butress thread testing, a right hand 7/45 butress thread insert, a left hand 7/45 butress thread insert, and a neutral A2 cut-off insert. A new threading insert was used for every experiment. Table 1 illustrates the details of the threading inserts and the cut-off inserts used during this evaluation. A picture of the threading insert is shown in Figure 1 and a picture of the cut-off insert is shown in Figure 2. The load flank angle, clearance angle, and nose radius of every insert was measured and documented for each experiment and are shown with the DOE test data in Appendices 1 and 2.

<u>Initial Butress Thread Machining Evaluation</u>			
Tool	Supplier	Description	Order Number
Thread Insert	Kennametal, Inc.	Top Notch Threading Insert American Butress – Pull 7°/45° – Right Handed 20 Threads per Inch Grade: KC5010	NTB2RB Grade: KC5010
Thread Insert	Kennametal, Inc.	Top Notch Threading Insert American Butress – Pull 7°/45° – Left Handed 20 Threads per Inch Grade: KC5010	NTB2LB Grade: KC5010
Cut-Off Insert	Kennametal, Inc.	A2 Cut-Off Insert Neutral Grade: KC5025	A2060N00CR03 Grade: KC5025

Table 1



Figure 1 – Threading Insert

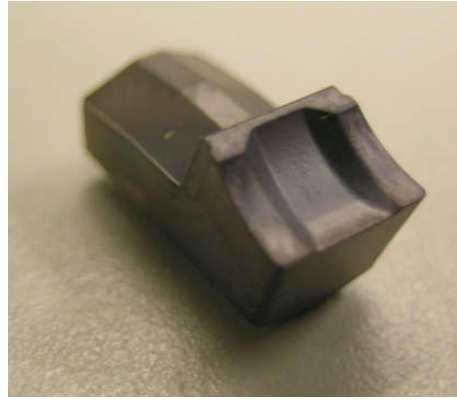


Figure 2 – Cut-Off Insert

3.2 External Buttress Thread DOE

The DOE for the external buttress thread cutting was initially setup to vary the machine cutting depth from 0.003" to 0.005" per pass at 0.001" increments. These depths were chosen because of recommendations from research documents, but it was later found that cutting depths of 0.001" to 0.003" were better suited for this test. The cutting speeds were 150, 200, and 300 surface feet per minute (SFM) and the feed rate for all of the experiments were held constant at 0.050 inches per revolution (IPR). These threads were machined using a Fryer Easy Turn lathe and Castrol Syntilo 9904 coolant. The threads were machined from the face of the part to the machine chuck. Each experiment required the 4340 steel materials received from Raytheon to be faced off. The segment of machined threads was to be at least 0.5" in length. This threaded portion was then sectioned off and is shown in Figure 3. The data can be found in Appendix 1.

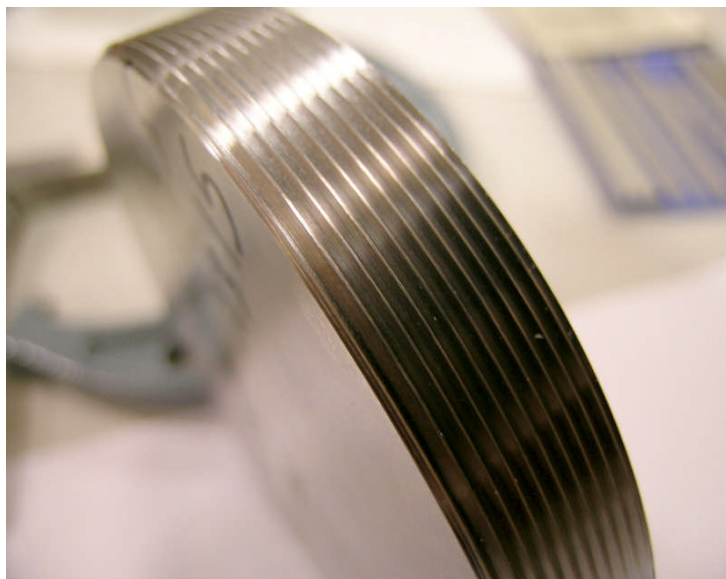


Figure 3 – External Threads

3.3 Internal Buttress Thread DOE

The DOE for the internal buttress thread cutting was setup to allow for 0.001” and 0.002” depths of cuts and cutting speeds of 150, 200, and 250 SFM. The feed rate for each DOE was held constant at 0.050 IPR. These threads were machined using a HAAS SL-20 lathe and Castrol Syntilo 9904 as the coolant. Each experiment required the 4340 steel materials received from Raytheon to be faced off. The threads were machined from the face of the part to the machine chuck. The segment of machined threads was to be at least 0.5” in length. This threaded portion was then sectioned off and is shown in Figure 4. The data can be found in Appendix 2.

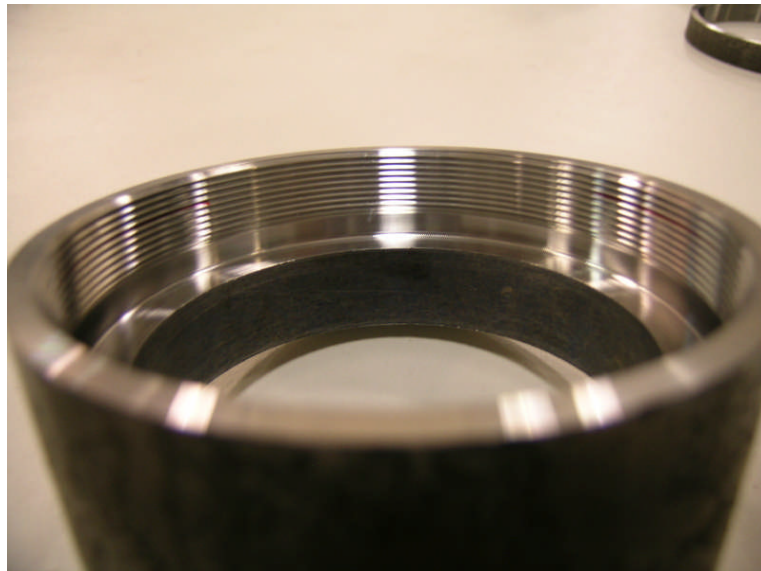


Figure 4 – Internal Threads

3.4 Dimensional Inspection

A total of six experiments were completed for each DOE test. After each internal thread experiment was completed, an inspection sample was cut from the threaded specimen in order for accurate measurements to be taken on the optical comparator. An inspection sample and the threaded specimen from which it was taken are shown in Figure 5. It was found that a 0.10” thick inspection sample reduced the amount of distortion created by viewing a round part on the optical comparator. The lead flank angle and the clearance flank angle were measured on an optical comparator as well. The pitch diameters for the external buttress threads were measured using the three-wire method and the major diameter was measured using standard micrometers. A Gagemaker PD-6000 series pitch diameter gage shown in Figure 6 was used to measure the pitch diameter of the internal threads. To obtain accurate measurements of the internal threads, Vinyl Polysiloxane was used to make a mold of the threads to be measured on an optical comparator. Figure 7 shows an illustration of the Vinyl Polysiloxane molded

sample used for the measurements. The Class III tolerances for all of the critical dimensions were calculated using the equations in the American National Standards ANSI B1.9-1992 and are shown in Appendix 3.



Figure 5 – Measurement Sample

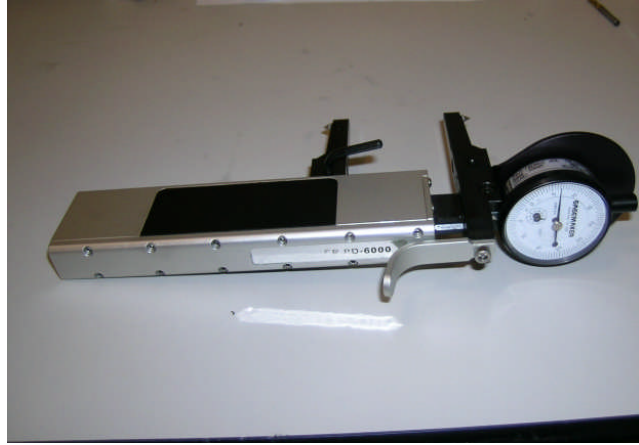


Figure 6 – Pitch Diameter Gage

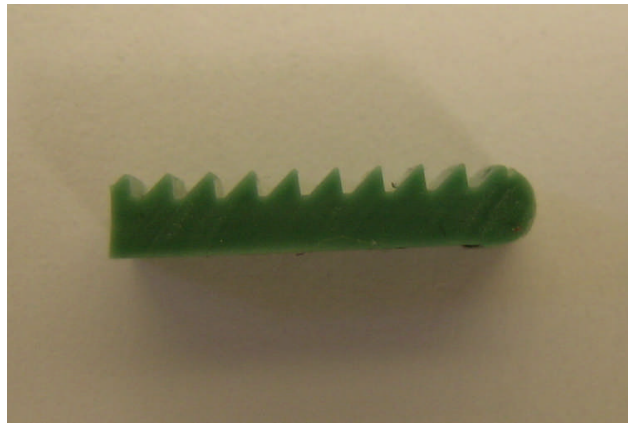


Figure 7 – Vinyl Polysiloxane Internal Thread Measurement Sample

4.0 Experimental Results

The result of each DOE performed on the internal and external buttress threads was that the NCDMM was able to successfully machine threads in 4340 steel that meet Class III requirements. The requirements for internal and external Class III threads are shown in Appendix 4.

4.1 External Buttress Threading

The results of the DOE for external buttress threading are shown in Appendix 1. DOE run number three performed the best out of the six experiments completed. The parameters used in run number three were a cutting speed of 200 SFM and a depth of cut per pass of 0.002". These parameters were chosen as the optimum

and were used to machine an additional sample and two pull test specimens. The two pull test specimens will be provided to Raytheon for additional testing at their facility. The dimensions for the externally threaded pull samples can be found in Appendix 5.

Lighter and heavier depths of cut were used in the DOE, but none achieved results as good as the 0.002" depth of cut. The heavy depth of cut was 0.003" per pass. This depth of cut caused the insert nose to break and it was determined that there was too much cutting pressure on the insert with this depth of cut. A 0.001" depth of cut was also tried, but excessive wear was experienced.

4.2 Internal Buttress Threading

The results of the DOE for internal buttress threading are shown in Appendix 2. DOE run number three performed the best out of the six experiments completed. The parameters used in number three were a cutting speed of 250 SFM and a depth of cut per pass of 0.002". These parameters were chosen as the optimum and were used to machine an additional sample and two pull test specimens. The two pull test specimens will be provided to Raytheon for additional testing at their facility. The dimensions for the internally threaded pull samples can be found in Appendix 6.

5.0 Conclusion

In conclusion, NCDMM has determined that to machine the required fine pitch (20 TPI) external and internal Class III, 7°/45° buttress threads, the following tooling and parameters are required:

5.1 External Buttress Threads

- Kennametal, Inc. Top Notch Threading Insert, American Buttress – Pull 7°/45°, Right Hand, 20 TPI, Grade KC5010, NTB2RB
- Kennametal, Inc. A2 Cut-off Insert, Grade KC5025, A2060N00CR03
- Cutting Speed: 200 SFM
- Depth of Cut: 0.002"
- Feed Rate: 0.050" IPR
- Threading performed using an Alternating Flank Tool Path.

5.2 Internal Buttress Threads

- Kennametal, Inc. Top Notch Threading Insert, American Buttress – Pull 7°/45°, Left Hand, 20 TPI, Grade KC5010, NTB2LB
- Kennametal, Inc. A2 Cut-Off Insert, Grade KC5025, A2060N00CR03
- Cutting Speed: 250 SFM
- Depth of Cut: 0.002”
- Feed Rate: 0.050” IPR
- Threading performed using an Alternating Flank Tool Path.

The above results have proven to be the successful solution to Raytheon’s ongoing problem of producing out of tolerance parts resulting in failures of these critical components. Producing the required components in the manner described herein will move Raytheon one step closer to eliminating the failures of the Excalibur Missile and the ERGM components.

5.3 Recommendations

- The NCDMM recommends Raytheon reduce the hardness of the 4340 steel to Rockwell C48 or below, allowing for a much easier machining process and extended tool life.
- The NCDMM recommends specifying a larger nose radius than what is called for in the Class III specification. The NCDMM feels this will reduce the stress concentrations in the threads, would allow for deeper cuts, increased cutting speeds, and also minimize the chipping of the thread cutting tool extending its usable life.
- The NCDMM recommends looking into the possibility of reducing the thread specification from Class III to Class II threads.

Appendix 1

External Thread DOE Results

DOE Run	Cutting Speed (SFM)	Number of Tool Passes	Depth of Cut (in)	Feed Rate (IPR)	Insert Type Used	Grade	New Insert (Yes / No)	Insert Identification Number	Insert Load Flank Angle Prior to Cut	Insert Clearance Flank Angle Prior to Cut	Insert Nose Radius (0.0018" - 0.0036")
1	150	11	0.003	0.050	NTB2RB	KC5010	Yes	1	4.0	47.0	0.0028
2	150	16	0.002	0.050	NTB2RB	KC5010	Yes	3	4.0	47.0	0.0028
3	200	16	0.002	0.050	NTB2RB	KC5010	Yes	2	4.0	47.0	0.0028
4	300	16	0.002	0.050	NTB2RB	KC5010	Yes	4	4.0	47.0	0.0028
5	150	32	0.001	0.050	NTB2RB	KC5010	Yes	5	4.0	47.0	0.0028
6	200	32	0.001	0.050	NTB2RB	KC5010	Yes	6	4.0	47.0	0.0028

Thread Cut Method	Component Thread Pitch Diameter (3.4608" - 3.4654")	Component Thread Major Diameter (3.4908" - 3.4954")	Component Thread Root Radius (0.0018" - 0.0036")	Component Thread Load Flank Angle (6.5 - 7.5 deg.)	Component Thread Clearance Flank Angle (44.5 - 45.5 deg.)	Chatter Present (Yes / No)	Actual Thread Cutting Time (min)
Alternating Flank	3.4630	3.4910	0.0056	10.0	45.0	No	1.00
Alternating Flank	3.4645	3.4950	0.0046	5.0	45.0	No	1.60
Alternating Flank	3.4640	3.4930	0.0027	7.0	45.0	No	1.60
Alternating Flank	3.4650	3.4925	0.0035	10.0	43.0	No	1.60
Alternating Flank	3.4640	3.4920	0.0050	6.0	45.0	No	3.50
Alternating Flank	3.4630	3.4935	0.0049	7.0	45.0	No	3.50

Appendix 2

Internal Thread DOE Results

DOE Run	Cutting Speed (SFM)	Number of Tool Passes	Depth of Cut (in)	Feed Rate (IPR)	Insert Type Used	Grade	New Insert (Yes / No)	Insert Identification Number	Insert Load Flank Angle Prior to Cut	Insert Clearance Flank Angle Prior to Cut	Insert Nose Radius (0.0018" - 0.0036")
1	150	16.5	0.002	0.050	NTB2LB	KC5010	Yes	1	4.0	48.0	0.0028
2	200	16.5	0.002	0.050	NTB2LB	KC5010	Yes	2	4.0	48.0	0.0032
3	250	16.5	0.002	0.050	NTB2LB	KC5010	Yes	3	4.0	48.0	0.0030
4	150	33.0	0.001	0.050	NTB2LB	KC5010	Yes	4	4.0	48.0	0.0024
5	200	33.0	0.001	0.050	NTB2LB	KC5010	Yes	5	4.0	48.0	0.0029
6	250	33.0	0.001	0.050	NTB2LB	KC5010	Yes	6	4.0	48.0	0.0026

Thread Cut Method	Component Thread Pitch Diameter (3.4700" - 3.4746")	Component Thread Minor Diameter (3.4400" - 3.4446")	Component Thread Root Radius (0.0018" - 0.0036")	Component Thread Load Flank Angle (6.5 - 7.5 deg.)	Component Thread Clearance Flank Angle (44.5 - 45.5 deg.)	Chatter Present (Yes / No)	Actual Cut Time (min)
Alternating Flank	3.4715	3.4430	0.0033	6.5	45.0	NO	2.10
Alternating Flank	3.4735	3.4430	0.0029	6.0	45.5	NO	2.00
Alternating Flank	3.4740	3.4430	0.0027	6.5	45.0	NO	1.50
Alternating Flank	3.4710	3.4430	0.0028	6.0	45.0	NO	3.44
Alternating Flank	3.4750	3.4430	0.0032	6.5	46.0	NO	3.34
Alternating Flank	3.4720	3.4430	0.0026	6.5	45.5	NO	3.24

Appendix 3

Buttress Thread Calculations from ANSI B1.9 1992

PD = Pitch Diameter

p = Pitch Diameter = 0.0500

D = Diameter = 3.500

Le = Length of Engagement

h = Basic Height of Thread = $0.6p$

Class II PD Tolerance = $[(0.002 \cdot D^{.3333}) + (0.00278 \cdot \sqrt{Le}) + (0.00854 \cdot \sqrt{p})]$

Class III = Class II PD Tolerance * .6667

Internal Threads

Minimum Pitch Diameter = $(D - h)$

Maximum Pitch Diameter = $((D - h) + \text{Class III Tolerance})$

Minimum Major Diameter = $(D + (0.12542 \cdot p))$

Minimum Minor Diameter = $(D - (2 \cdot h))$

Maximum Minor Diameter = $(\text{Minimum Minor Diameter} + \text{Class III Tolerance})$

External Threads

Maximum Pitch Diameter = $((D - h) - \text{Class III Tolerance})$

Minimum Pitch Diameter = $((D - h) - \text{Class III Tolerance}) - \text{Class III Tolerance}$

Maximum Major Diameter = $(D - \text{Class III Tolerance})$

Minimum Major Diameter = $(D - (2 \cdot \text{Class III Tolerance}))$

Maximum Minor Diameter = $((D - \text{Class III Tolerance}) - (2 \cdot 0.66271 \cdot p))$

Root Radius

Maximum Root Radius = $0.07141p$

Minimum Root Radius = $0.0357p$

Appendix 4

External Buttress Thread Requirements

Insert Nose Radius: 0.0018" to 0.0036"

Component Thread Pitch Diameter: 3.4608" to 3.4654"

Component Thread Minor Diameter: 3.4908" to 3.4954"

Component Thread Root Radius: 0.0018" to 0.0036"

Component Thread Load Flank Angle: 6.5° to 7.5°

Component Thread Clearance Flank Angle: 44.5° to 45.5°

Internal Buttress Thread Requirements

Insert Nose Radius: 0.0018" to 0.0036"

Component Thread Pitch Diameter: 3.4700" to 3.4746"

Component Thread Minor Diameter: 3.4400" to 3.4446"

Component Thread Root Radius: 0.0018" to 0.0036"

Component Thread Load Flank Angle: 6.5° to 7.5°

Component Thread Clearance Flank Angle: 44.5° to 45.5°

Appendix 5

Details for Externally Threaded Pull Test Parts

Test Pieces	Cutting Speed (SFM)	Number of Tool Passes	Depth of Cut (in)	Feed Rate (IPR)	Insert Type Used	Grade	New Insert (Yes / No)	Insert Identification Number	Insert Load Flank Angle Prior to Cut	Insert Clearance Flank Angle Prior to Cut	Insert Nose Radius (0.0018" - 0.0036")
PT 1	200	16	0.002	0.050	NTB2RB	KC5010	Yes	11	4.0	47.0	0.0028
PT 2	200	16	0.002	0.050	NTB2RB	KC5010	Yes	12	4.0	47.0	0.0028
PT 3	200	16	0.002	0.050	NTB2RB	KC5010	Yes	Other Side of 11	4.0	47.0	0.0028
SMP 7	200	16	0.002	0.050	NTB2RB	KC5010	Yes	Other Side of 6	4.0	47.0	0.0028

Thread Cut Method	Component Thread Pitch Diameter (3.4608" - 3.4654")	Component Thread Major Diameter (3.4908" - 3.4954")	Component Thread Root Radius (0.0018" - 0.0036")	Component Thread Load Flank Angle (6.5 - 7.5 deg.)	Component Thread Clearance Flank Angle (44.5 - 45.5 deg.)	Chatter Present (Yes / No)	Actual Thread Cutting Time (min)
Alternating Flank	3.4635	3.4930	0.0000	6.5	45.0	No	1.60
Alternating Flank	3.4640	3.4930	0.0000	6.0	45.0	No	1.60
Alternating Flank	3.4640	3.4930	0.0000	6.5	45.0	No	1.60
Alternating Flank	3.4640	3.4935	0.0000	6.5	45.0	No	1.60

Appendix 6

Details for Internally Threaded Pull Test Parts

Test Pieces	Cutting Speed (SFM)	Number of Tool Passes	Depth of Cut (in)	Feed Rate (IPR)	Insert Type Used	Grade	New Insert (Yes / No)	Insert Identification Number	Insert Load Flank Angle Prior to Cut	Insert Clearance Flank Angle Prior to Cut	Insert Nose Radius (0.0018" - 0.0036")
PT 1	250	16.5	0.002	0.050	NTB2LB	KC5010	Yes	8	4.0	48.0	0.0026
PT 2	250	16.5	0.002	0.050	NTB2LB	KC5010	Yes	9	4.0	48.0	0.0025
SMP. 7	250	16.5	0.002	0.050	NTB2LB	KC5010	Yes	7	4.0	48.0	0.0033

Thread Cut Method	Component Thread Pitch Diameter (3.4700" - 3.4746")	Component Thread Minor Diameter (3.4400" - 3.4446")	Component Thread Root Radius (0.0018" - 0.0036")	Component Thread Lead Flank Angle (6.5 - 7.5 deg.)	Component Thread Clearance Flank Angle (44.5 - 45.5 deg.)	Chatter Present (Yes / No)	Actual Cut Time (min)
Alternating Flank	3.4715	3.4430	0.0035	6.5	45.0	NO	1.50
Alternating Flank	3.4710	3.4430	0.0033	6.5	45.0	NO	1.50
Alternating Flank	3.4710	3.4430	0.0035	6.5	45.0	NO	1.50