



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED. Analysis of Fatigue Life Estimate for the M119 Cradle Assembly with a Gouge Cut Defect

Caitlin Weaver, Robert K. Terhune, Brian Peterson

AMSRD-AAR-MEF-E, Building 94, 2nd floor Fuze and Precision Armaments Directorate AETC, U.S. Army ARDEC, Picatinny Arsenal, NJ 07806-5000 phone: 973-724-6349, fax: 973-724-2417, <u>caitlin.m.weaver@us.army.mil</u>

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I. Background





- During the manufacturing process in 2011, 46 M119A2 systems were manufactured with a tooling groove defect in the 12593242 Cradle.
- The worst case tooling groove was 0.071-in deep and 2.300-in long, spanning the full length of the channel.

• <u>Goals:</u>

- Run a fatigue and critical crack analysis on the modeled portion of the plate that has the tooling defect (gouge).
- Determine if cradle will survive for 1100 cycles (per reliability requirement MIL-DTL-32191).
- Determine if further analysis is needed.

• <u>Scope:</u>

- The primary concern of the analysis effort is to analyze M119 cradle components specifically the firing mechanism plate of the cradle channel.
- The model is loaded by pressure data calculated from strain gauge data that was recorded during live fire testing.

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I. Background (cont.)



***Note: Cradle critical components labeled, individual parts not specified below





II.a. Method - Abaqus: Geometry, Part instances, BC, Materials and Loads



- Analysis was performed using Abaqus 6.11
 - Analyses types: Dynamic implicit (XFEM) and explicit, non-linear materials, non-linear geometry
 - All models were meshed with 8-node hexahedral elements (C3D8R).
- To simulate the fixed position of the channel on the cradle:
 - the bottom face of the plate in the x-z plane was constrained in all directions and rotations using an Encastre boundary condition.
 - the top face in the x-z plane was constrained directionally and rotationally in the z-direction.
- Load:
 - the top face in the x-z plane was partitioned evenly into three equal parts.
 - the pressure load from the recorded test data was applied to the corresponding left, middle and right part of the top face of the x-z plane.
- Material used: 95-15 Stainless Steel.
 - Material property data was obtained from in house testing.



RDECOM II.b. Method – Abaqus: Pre-Cracked Simulations



- To insert a crack into the model:
 - Create a planar shell with dimensions needed for desired crack size (Part Module).
 - Translate the crack instance to desired location, making sure that it doesn't correspond to an element edge.



Example of a Crack in Finite Element Mesh

- Two pre-cracked models were used for XFEM simulation:
 - Case (1): a crack 0.015 x 0.011 inch horizontally along the gouge cut.
 - Case (2): a crack 0.015 x 0.011 inch vertically along the gouge cut.
- These pre-cracked models were done based off the results of a florescent penetrant test performed at YPG on 11 June 2011 that showed the presence of a 0.015 inch crack in the tooling defect area.



II.c. Method - Abaqus: Load Data

Applied Pressure Data



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RDECOM III.a. Method – Fe-Safe: Material Property and Load Data



- Analysis was performed using Fe-Safe version 6.2
 - Analysis type: imported dynamic explicit Abaqus analysis
- Material Used: SAE 4140
 - Ultimate tensile strength: 156,060 psi (very similar to 95-15 SS)
- Load Settings:
 - Step 1 at time = 0.2s, peak stress = 154,719, load scale: 0, 1;
 repeats = 5 (to simulate the reverbating from gun launch)



III.b. Method – Fe-Safe: Analysis Summary



슨 FEA Fatigue Analysis S	ummary
Algorithm	BrownMiller:-Morrow
Material	SAE-4140-system.dbase
Surface	75 um < Ra-default.kt
Kt	2.45
UTS	156.055 ksi
Subgroup	Surface
Knock-Down	Off
Model File (s)	C:\Abqwork\M119_fs_cmw_13feb12_2fesafe.odb
FEA Units	S=psi
Loading	Loading is equivalent to 1 Repeats
	Load Definition File : current.ldf
	Elastic FEA
Scale factor	1
Overflow Life value	0
Infinite Life value	Material CAEL
Temperature analysis	Enabled if temperatures present
Histories	None
Log	None
List of Items	None
Histories for Items	None
Log for Items	None
Output contours to	C:\Users\caitlin.m.weaver\Documents\fe-safe.version.6.2\projects\project_01\jobs\job_01\fe-results\M119_fs_cmw_13feb
Contour variables	LOGLife-Repeats, SMAX/Vield, SMAX/UTS
Intermediate	C:\Users\caitlin.m.weaver\Documents\fe-safe.version.6.2\projects\project_01\jobs\job_01\fe-results\fesafe.fer
Influence coeffs.	Disabled
Gauges.	Disabled
Solvers	Embedded Solver
•	
	Continue Cancel



IV.a. Method – NASGRO: Geometry, Material Property, and Normalized Stress Data







Thickness, t	0.08
Width, W	2.35
Crack ctr offset, B	1.175
Initial flaw size, a	0.0375291
Initial a/c	0.375291

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- Analysis was performed using NASGRO version 5.0
- Model used was surface crack plate specimen (SC17) with the same dimensions as the plate measured in Abaqus
 - Model was chosen after consultation with J. Cardinal (staff engineer at SwRI)
- Materials: 95-15 Stainless Steel (from in-house testing) and 15-5PH H1025 Stainless Steel (defined in NASGRO)

Normalized X	Normalized S0	Stress from Abaqus ODB
0	1	154808
0.1	0.989083252	153118
0.2	0.967068885	149710
0.3	0.823122836	127426
0.4	0.577328045	89375
0.5	0.380914423	58968.6
0.6	0.221089349	34226.4
0.7	0.105762622	16372.9
0.8	0.142635394	22081.1
0.9	0.322923234	49991.1
1	0.427379722	66161.8

RDECOM IV.b. Method - NASGRO: Loads

🕂 Geometry 📄 🕂 Geom Tables 🗎 📈 🛚 M	laterial	🔼 Los	d Blocks	BuildSch	edule 🗎 🎦 C	utputOptions	😴 Computa	tions
Show list of frequently-used schedules Add schedule to frequently-used list Visualize current block (1 of 1)						lock (1 of 1)		
Right-click to set number of distinct blocks Left-click to select which block to edit/display	Block Ca Enter the	ase Definitio number of (n: block 1 o cycles and v	f 1 alues for all stre	ess quantities:	1	1	1.
1 2 3 4 5 6 7 8 9 ↓	Step 1	Keac chk /	Lycies 1	1	0 SU at t2			â
For this block	2							
Input cycles and stresses manually Select file(e) containing long block(e)	4							
C Generate standard long block	6							-
○ Generate acceptance vibration block III III Stress scale factor on stress quantity S0 154.808 Set all blocks' scale factors to those of block 1								
Check throughout this block for crack instability at limit stress? Check if Kmax>Keac for this block? Keac								
Image: Bypass all net-section stress checks? Image: Blocks represent flights Blocks represent flight hours								

 Screen shot of load blocks used for analysis; S0 = 154,808 psi corresponds to the value from the Abaqus analysis; load corresponds to 1 cycle.

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RDECOM IV.c. Method – NASGRO: Cycle Schedule

⊕ '	Geometry 🕴 🕂	Geom Tables 🛛 🛃	Mater	ial 🛛 🕅 Load	Blocks MBui	ildSchedule	OutputOptions			
Ass	Assemble Schedule from Distinct Block Cases									
Sum	mary of distinct block	s already defined:		Distinct block case	repetition table:	Schedule title [optional]				
	Block type	Details	*	Block case	Times to apply	*				
1	Manual	no details available	=	1	1	= #o	f times to repeat schedule 1000			
2										
3			1							
4			1							
5			1							
6			1							
7			1							
8			1							
9			-			Ŧ				
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Screen shot of build schedule; each load block is applied 1 time for 1000 cycles.

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V.a. Results - XFEM





- The crack grows along the x-direction and varies between one and three elements through the thickness of the y-z plane.
- Value of 0.4 shows partial or surface cracking, not a complete through crack.

RDECOM V.b. Results – XFEM pre-crack (X-axis)



Crack at t=0s

Crack at t=1s

- The crack grows along the x- and z- direction.
- Crack propagation is similar to the crack initiation case.
- Crack is partial or surface cracking, not a complete through crack (based on the color values).

RDECOM V.C. Results – XFEM pre-crack (Y-axis)



Crack at t=0s



- The crack grows along the x- and z- direction; no crack growth in the y-direction.
- Crack propagation is not similar to the crack initiation case.
- Crack is partial or surface cracking, not a complete through crack (based on the color values).

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V.d. Results – Maximum Stress and Plastic Strain





- Crack initiation occurs at a Von Mises stress of 144,562 psi, which is slightly lower than the yield stress of the material
 - As the crack continues to propagate yield stress is reached
- Plastic strain was not exceeded

RDECOM



V.e. Results - fe-safe





• Analysis shows a life cycle of 1071

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V.f. Results - NASGRO



- Results show that crack
 becomes unstable after 106
 cycles
 - Crack grows to 0.072-in before failure, which is almost the thickness of the part.
 - Part thickness is 0.080-in

Save+Run Stop	Crack outside solution bounds: a/t = 0.9015 Valid Range 0	to 0.9
Select details to show:		
Input: Geometry Input: Material Input: Spectrum Sched/blk/step #	at the very beginning of Load Step No. 1 of Block No. 1 of Schedule No. 107	
Flights or flt hrs Crack size	Crack Sizes: a = 0.721207E-01 , c = 0.159205 , a/c = Total Cycles = 106.00000 # Total Flights = 106.00000	0.4530
Select details to plot:		
Crack size		
Max K	General spectrum diagnostics	
Beta factor, F		
Net stress fctr, G		
Residual strength		=
da/dN	Execution time (nn:mm:ss): 00:00:03.5	
DKth	Note: this is elapsed wall-clock time, not CPU time!	
Plot v. N v. a v. fits		-
		•
ALL calc'd data to csv file	Print window Close window Save window contents to doc file	

Computed output for "nasfla_M119.in"



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Conclusions:

- Results from all three methods show that the plate specimen fails the reliability requirement of 1100 mean rounds.
- The plate specimen was not able to prove that the channels with the tooling defects would survive the required amount of firings/cycles.

Path Forward (suggested):

• Since the plate specimen was not able to prove survivability, a more accurate FEA model needs to be analyzed in Abaqus and fe-safe to determine of the firing mechanism plate/channel would survive in the cradle assembly.



Questions





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