ABRAMS WIDTH CORRECTION FACTOR ASSESSMENT

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INTRODUCTION

A study was performed to assess the width correction factor (WCF) used in the calculation of the Military Load Class (MLC) of the Abrams tank. The study was performed in response to various discussions that have taken place regarding the potential need for change in how the WCF is applied in NATO STANAG 2021. The study looks at the maximum WCF used to determine the final MLC at various tank weights, using both actual vehicle weights for the vehicle that have been collected over the years and theoretical vehicle weights that were used to fill out the data set.

This study builds on a previous study, performed in 2013 for the Product Manager Abrams office, to assess how the MLC of the Abrams tank changed with increases in vehicle weight. The results of the study, extended since the initial study was completed to cover weights as low as 10 tons, is presented in graphical form in Figure 1. Figure 1 indicates that the MLC of the tank is equal to the tank's weight at weights up to 70 tons. Beyond 70 tons, the MLC deviates from the weight, and the amount of deviation increases the more the weight of the tank is increased. At the time the study was performed, it was believed that the vehicle's geometry, in the form of the width correction factor used for the MLC calculation, was the primary reason for this difference. However, no further analysis was performed up to now to validate that claim. The study documented in this paper looks at the claim from the 2013 study further. Presented in this paper is the procedure used for the study, as well as the results and associated discussion.

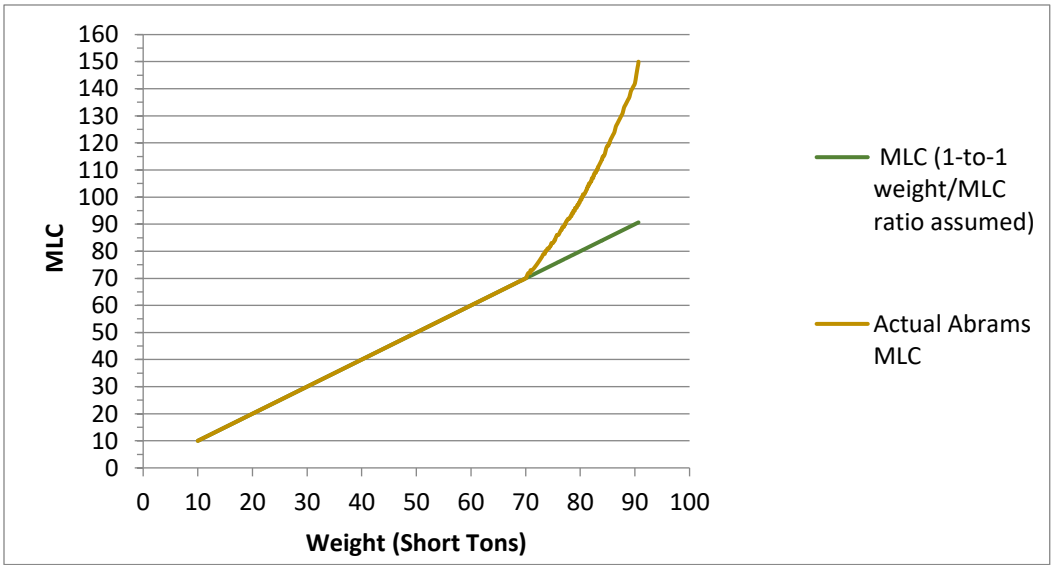

Figure 1: Abrams MLC Deviates from 1-to-1 Ratio from Vehicle Weight at Weight of 70 Tons

ANALYTICAL PROCEDURE

The study was performed by calculating the MLC of the Abrams tank at a total of 186 vehicle weight values, ranging from 10 short tons to 90.65 short tons. 90.65 short tons represents the weight at which

the MLC of the Abrams equals 150. The official MLC software mandated by the current version of NATO STANAG 2021 was used for all MLC calculations. The final rounded MLC, as well as the maximum unrounded MLC before and after width correction, was recorded, and the unrounded MLC values were used for further analysis. The MLC before width correction is referred to hereafter as the "uncorrected MLC", while the MLC after width correction is referred to hereafter as the "corrected MLC". The width correction factor used for each MLC calculation was then calculated using the following relationship:

$$WCF = \frac{Corrected\ MLC}{Uncorrected\ MLC} \quad (1)$$

Table 1 presents the tank dimensions used for all MLC calculations in this study. These dimensions have been used in previous MLC calculations for the Abrams tank and have been verified for use by the Product Manager Office that manages the tank.

Outside-to-Outside Track Width (in)	137.01
Track Length (in)	180.2

Table 1: Abrams Dimensions Used for MLC Calculations

RESULTS AND DISCUSSION

Figure 2 shows a plot of the uncorrected and corrected MLC with respect to vehicle weight, and the data from this study is provided in Appendix A. Similar to the behavior shown in Figure 1, the uncorrected and corrected MLC are initially equal, thus indicating that no WCF is applied in the calculation. A WCF begins to be applied to the MLC calculation at a weight of roughly 69 short tons and, based off of the increasing deviation between the two plots, it can be concluded that the WCF increases the further the weight is increased beyond 69 short tons. The data provided in Appendix A indicates that the WCF for the Abrams tank begins to exceed a value of 1.05 at a weight of 76 short tons. For the purposes of this study, 1.05 is the minimum value at which the effect of the WCF is considered to have a significant effect on the overall vehicle MLC. Of the 186 weights used in the study, 135 of them had a WCF that exceeded 1.05.

Table 2 shows statistical results for all of the data points used in this study. The maximum WCF resulted at a vehicle weight of 90.65 short tons, while the minimum WCF occurs at weights lower than 69 tons. At the weights where the minimum WCF occurs, a WCF is not applied in the MLC calculation because the width of the Abrams exceeds that of the comparable hypothetical vehicles in NATO STANAG 2021. The resulting average WCF for the full data set, along with the number of weight values with WCF values exceeding 1.05, indicate that, from an overall perspective, the WCF is more likely than not to have a significant effect on the final MLC of the Abrams. This causes the MLC of the Abrams to be much higher than what would result if the calculation was based solely on the bending moment and shear force values calculated as part of the vehicle MLC calculation process.

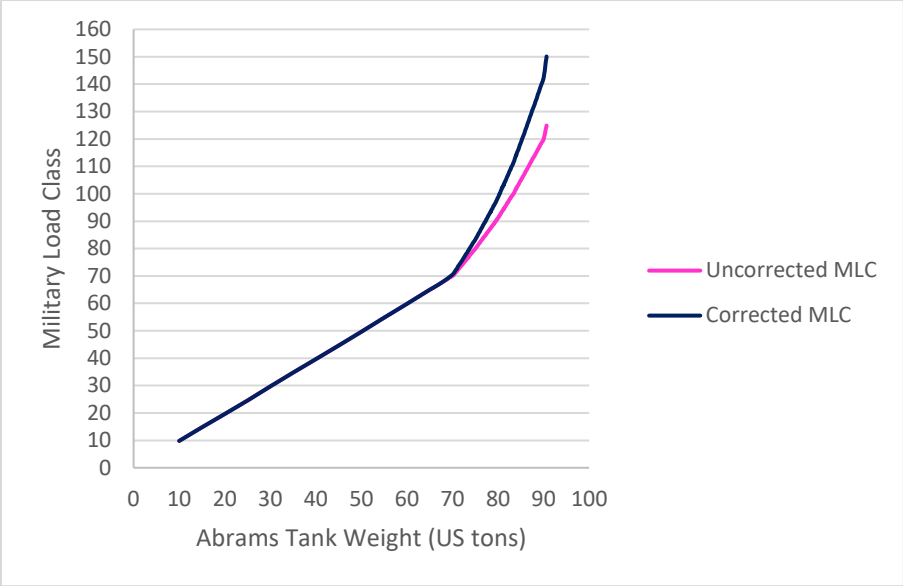

Figure 2: Deviation of Corrected MLC from Uncorrected MLC Increases with Increasing Weight

Min WCF	1.00
Max WCF	1.20
Average WCF	1.08
Standard Deviation	0.05

Table 2: Statistical Results for All Data Points in Study

To further assess the significance of the results, data from the current Abrams variant, designated as System Enhanced Package v3 (SEPv3), was evaluated separately from the rest of the data. Figure 3 shows a plot of the uncorrected and corrected SEPv3 MLC with respect to vehicle weight. These MLCs were calculated using actual weights, current as of April 2020, for SEPv3 configurations deemed by the United States Army as being operationally relevant for bridge crossings. These configurations include the use of various add-on equipment, to include armor, countermine equipment and active protection systems. Observation of Figure 3 indicates that the MLC of the SEPv3 behaves in a similar fashion to the overall data set, with the difference between the uncorrected MLC and corrected MLC increasing as the weight of the vehicle increases.

Figure 3: Corrected vs Uncorrected MLC Behavior for Abrams SEPv3 Similar to That Seen for Full Data Set

Table 3 shows the numerical data for the SEPv3 configurations used in the study, including the uncorrected and corrected MLCs presented in Figure 3, while Table 4 presents statistical data for the SEPv3 data set. As the data in Table 3 shows, the WCF exceeds the significance threshold of 1.05 for all but one of the configurations, while the average WCF for the SEPv3 data set presented in Table 4 is close to that for the entire data set given in Appendix A. This indicates that, similar to what was observed for the entire data set, the WCF significantly affects the final MLC of the Abrams SEPv3 by resulting in a much higher MLC than that resulting from the calculated bending moments and shear forces.

The case of the SEPv3 helps to highlight the issue causing the problem with the WCF for the Abrams. As indicated in Table 3, different tank configurations are produced to address various missions by adding weight, in the form of a variety of add-on kits, to the tank. From an MLC perspective, the increased weight results in an increase in the uncorrected MLC that results from the calculation, and the uncorrected MLC will continue to increase if the vehicle weight continues to increase. The increasing uncorrected MLC results in an increase in the hypothetical vehicle width being used for the width comparison, as the hypothetical tracked vehicle widths provided in NATO STANAG 2021 increase with increasing MLC. However, these weight additions are not accompanied by changes to the vehicle's

footprint, specifically the vehicle's outside track-to-outside track width. This lack of change to the vehicle's width, combined with the increase in the hypothetical vehicle width used for the comparison, results in a progressive increase in the WCF with increasing vehicle weight and, subsequently, an increased effect to the vehicle's final MLC. This issue will likely continue to exist, as it is easier to add weight to the vehicle than it is to change its footprint.

The increased effect of the WCF on a vehicle's final MLC can have an adverse impact on military operations, preventing the vehicle from crossing bridges that it may otherwise be able to cross based off of static analysis. This can also affect the acquisition and design of future bridges. MLC requirements for military bridges are normally based off of the MLC of the heaviest vehicle for which it is being procured to support. The bridge design process will also include evaluation of the bridge design for eccentric crossings, with the vehicle footprint placed at various positions along the bridge's width. This evaluation includes placement of the vehicle footprint at the most extreme position, which the WCF attempts to account for in the MLC calculation. These two factors ultimately lead to the eccentric effect being double counted in the design process, which results in a bridge that is overdesigned for its intended purpose. This overdesign can drive up the weight of the bridge, putting more of a burden on the bridge's carrier vehicle and affecting the overall durability of the bridge's launch and retrieval mechanism. This can also drive up the cost of the system, resulting in fewer systems being procured or the program being terminated altogether. While it is acknowledged that additional cases may be required to affect change in the use of the WCF within the parameters of NATO STANAG 2021, it is also acknowledged that the case presented here is a significant one, as the Abrams tank is the main battle tank for the United States. Any restrictions to the mobility of the Abrams tank can adversely affect the ability of the United States and its allies to successfully complete a mission. The significance of the effect of the WCF on the MLC of the Abrams tank, especially on the SEPv3, indicates that, at a minimum, further evaluation of the WCF and its application for vehicle and bridge MLC evaluations is warranted.

Configuration	Weight (US Tons)	Final MLC	Uncorrected MLC	Corrected MLC	Width Correction Factor
1	73.494	79	76.87	79.287	1.031
2	77.1975	90	84.809	89.86	1.060
3	78.3615	93	87.403	93.41	1.069
4	78.4735	94	87.652	93.754	1.070
5	78.666	94	88.082	94.349	1.071
6	79.6375	97	90.287	97.415	1.079
7	80.3325	100	92.095	99.954	1.085
8	80.9775	102	93.772	102.332	1.091
9	81.4965	104	95.122	104.26	1.096
10	81.6085	105	95.413	104.677	1.097
11	82.1415	107	96.8	106.673	1.102
12	82.7725	109	98.441	109.054	1.108
13	84.1125	115	102.22	114.638	1.121
14	85.2765	120	105.714	119.904	1.134

Table 3: Abrams SEPv3 Analysis Results

Min WCF	1.03
Max WCF	1.13
Average WCF	1.09
Standard Deviation	0.03

Table 4: Statistical WCF Results for Abrams SEPv3

CONCLUSION

An analysis was performed to assess the WCF used for the MLC calculation of the Abrams tank. A total of 186 data points were used for the total analysis, while 14 data points were used for a separate analysis of the WCF for the SEPv3, the current version of the tank. Both series of analyses indicates that, overall, the WCF has a significant effect on the MLC of the tank, resulting from the increase in vehicle weight without associated changes to its footprint. This effect could have negative impacts on the tank's mobility, as well as on the design of future military bridging systems. Because of these impacts, it is concluded that a further evaluation of the WCF and its application is warranted.

APPENDIX A: ANALYSIS DATA

Weight (US Tons)	MLC	Uncorrected MLC	Corrected MLC	Width Correction Factor
10	10	9.799	9.799	1.00
15	15	14.749	14.749	1.00
20	20	19.661	19.661	1.00
25	25	24.59	24.59	1.00
30	30	29.642	29.642	1.00
35	35	34.647	34.647	1.00
40	40	39.649	39.649	1.00
45	45	44.676	44.676	1.00
50	50	49.705	49.705	1.00
55	55	54.764	54.764	1.00
60	60	59.825	59.825	1.00
65	65	64.912	64.912	1.00
66	66	65.929	65.929	1.00
67	67	66.947	66.947	1.00
68	68	67.964	67.964	1.00
68.96	69	68.941	69.157	1.00
69	69	68.982	69.208	1.00
70	70	69.999	70.498	1.01
70.25	71	70.299	70.874	1.01
70.5	72	70.802	71.508	1.01
70.75	72	71.309	72.147	1.01
70.8795	72	71.57	72.478	1.01
70.89	73	71.592	72.506	1.01
71	73	71.815	72.789	1.01
71.2	73	72.221	73.303	1.01
72	75	73.842	75.373	1.02
73	78	75.869	77.986	1.03
73.25	79	76.375	78.644	1.03
73.4325	79	76.744	79.124	1.03
73.46	79	76.801	79.198	1.03
73.494	79	76.87	79.287	1.03
73.5	79	76.882	79.303	1.03
73.6	80	77.085	79.568	1.03
73.71	80	77.308	79.859	1.03
73.75	80	77.389	79.965	1.03
73.765	80	77.419	80.004	1.03
74	81	77.895	80.628	1.04
74.25	81	78.402	81.293	1.04

74.5	82	78.909	81.96	1.04
74.583	82	79.077	82.182	1.04
74.5965	82	79.103	82.216	1.04
74.7085	83	79.33	82.516	1.04
74.75	83	79.415	82.629	1.04
75	83	79.922	83.299	1.04
75.25	84	80.471	84.028	1.04
75.352	84	80.699	84.33	1.04
75.5	85	81.028	84.769	1.05
75.747	86	81.579	85.504	1.05
75.75	86	81.585	85.513	1.05
75.859	86	81.828	85.838	1.05
75.8725	86	81.857	85.877	1.05
76	86	82.142	86.259	1.05
76.25	87	82.699	87.007	1.05
76.5	88	83.256	87.757	1.05
76.516	88	83.292	87.805	1.05
76.628	88	83.542	88.142	1.06
76.75	89	83.813	88.509	1.06
77	89	84.37	89.264	1.06
77.023	89	84.422	89.333	1.06
77.18	90	84.771	89.809	1.06
77.1975	90	84.809	89.86	1.06
77.2125	90	84.843	89.906	1.06
77.25	90	84.927	90.021	1.06
77.4135	91	85.291	90.515	1.06
77.4685	91	85.413	90.682	1.06
77.5	91	85.484	90.78	1.06
77.75	92	86.041	91.541	1.06
77.792	92	86.135	91.669	1.06
78	92	86.598	92.304	1.07
78.25	93	87.155	93.07	1.07
78.2735	93	87.207	93.14	1.07
78.344	93	87.365	93.358	1.07
78.3615	93	87.403	93.41	1.07
78.363	93	87.407	93.417	1.07
78.3765	93	87.436	93.456	1.07
78.456	94	87.614	93.702	1.07
78.4735	94	87.652	93.754	1.07
78.5	94	87.712	93.838	1.07
78.5775	94	87.884	94.074	1.07

78.6325	94	88.007	94.244	1.07
78.666	94	88.082	94.349	1.07
78.6895	94	88.134	94.419	1.07
78.7445	95	88.256	94.589	1.07
78.75	95	88.269	94.607	1.07
78.92	95	88.648	95.132	1.07
79	95	88.826	95.38	1.07
79.0425	96	88.92	95.51	1.07
79.08	96	89.005	95.627	1.07
79.132	96	89.121	95.788	1.07
79.16	96	89.183	95.875	1.08
79.25	96	89.383	96.154	1.08
79.3225	96	89.544	96.377	1.08
79.4375	97	89.8	96.735	1.08
79.5	97	89.94	96.931	1.08
79.527	97	90.001	97.015	1.08
79.5495	97	90.058	97.095	1.08
79.62	97	90.243	97.353	1.08
79.6375	97	90.287	97.415	1.08
79.75	98	90.581	97.826	1.08
79.8535	98	90.849	98.201	1.08
79.9085	98	90.992	98.402	1.08
80	99	91.231	98.738	1.08
80.2015	99	91.754	99.474	1.08
80.2065	99	91.767	99.492	1.08
80.25	100	91.881	99.654	1.08
80.296	100	92.001	99.822	1.09
80.3185	100	92.058	99.903	1.09
80.3325	100	92.095	99.954	1.09
80.4175	100	92.316	100.267	1.09
80.4865	101	92.495	100.52	1.09
80.5	101	92.532	100.572	1.09
80.5985	101	92.786	100.933	1.09
80.7135	101	93.086	101.356	1.09
80.75	101	93.182	101.493	1.09
80.96	102	93.728	102.269	1.09
80.9775	102	93.772	102.332	1.09
81	102	93.832	102.417	1.09
81.1935	103	94.334	103.133	1.09
81.2485	103	94.477	103.337	1.09
81.25	103	94.482	103.344	1.09

81.3655	104	94.781	103.772	1.09
81.4775	104	95.073	104.189	1.10
81.4825	104	95.086	104.208	1.10
81.4965	104	95.122	104.26	1.10
81.5	104	95.133	104.275	1.10
81.5815	105	95.343	104.577	1.10
81.6085	105	95.413	104.677	1.10
81.6935	105	95.635	104.995	1.10
81.75	105	95.783	105.208	1.10
81.7625	105	95.814	105.253	1.10
82	106	96.433	106.144	1.10
82.0535	106	96.571	106.343	1.10
82.124	107	96.756	106.61	1.10
82.1415	107	96.8	106.673	1.10
82.25	107	97.083	107.083	1.10
82.3575	107	97.362	107.486	1.10
82.4125	108	97.505	107.693	1.10
82.5	108	97.734	108.025	1.11
82.6415	109	98.1	108.558	1.11
82.75	109	98.384	108.971	1.11
82.7725	109	98.441	109.054	1.11
82.8225	109	98.571	109.243	1.11
82.8575	109	98.662	109.376	1.11
83	110	99.034	109.919	1.11
83.1025	110	99.299	110.307	1.11
83.2175	111	99.598	110.744	1.11
83.25	111	99.684	110.87	1.11
83.5	112	100.386	111.904	1.11
83.75	113	101.136	113.018	1.12
83.9815	114	101.829	114.05	1.12
83.9865	114	101.844	114.073	1.12
84	114	101.886	114.136	1.12
84.1125	115	102.22	114.638	1.12
84.1975	115	102.477	115.019	1.12
84.25	115	102.636	115.257	1.12
84.2665	115	102.684	115.329	1.12
84.5	116	103.386	116.383	1.13
84.75	118	104.136	117.513	1.13
85	119	104.886	118.647	1.13
85.1455	119	105.321	119.307	1.13
85.25	120	105.636	119.786	1.13

85.2765	120	105.714	119.904	1.13
85.3615	120	105.969	120.292	1.14
85.5	121	106.386	120.928	1.14
85.75	122	107.136	122.075	1.14
86	123	107.886	123.225	1.14
86.25	124	108.636	124.38	1.14
86.5	126	109.386	125.539	1.15
86.75	127	110.136	126.702	1.15
87	128	110.886	127.869	1.15
87.25	129	111.636	129.04	1.16
87.5	130	112.386	130.215	1.16
87.75	131	113.136	131.395	1.16
88	133	113.886	132.578	1.16
88.25	134	114.636	133.766	1.17
88.5	135	115.386	134.958	1.17
88.75	136	116.137	136.154	1.17
89	137	116.887	137.354	1.18
89.25	139	117.637	138.558	1.18
89.5	140	118.387	139.766	1.18
89.75	141	119.137	140.978	1.18
90	142	119.887	142.195	1.19
90.25	145	121.696	145.041	1.19
90.5	148	123.694	148.199	1.20
90.6	149	124.493	149.469	1.20
90.65	150	124.892	150.106	1.20