A STUDY ON THE RELATIONSHIP BETWEEN A WHEELED VEHICLE'S LONGITUDINAL CENTER OF GRAVITY LOCATION AND ITS MILITARY LOAD CLASS

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ABSTRACT

A study was performed to assess the effect of changes to a wheeled vehicle's longitudinal center of gravity (CG) location on its Military Load Class (MLC). A series of MLC calculations was performed for three different wheeled military vehicles, using a North Atlantic Treaty Organization (NATO) defined methodology as well as both base and modified axle spacing values. The maximum calculated MLC and longitudinal CG location was recorded for each set of axle spacing values. The results were then analyzed to determine how the maximum MLC for each vehicle varied with respect to different longitudinal CG location values. Analytical results are presented in this paper, along with the conclusions resulting from the study.

1. INTRODUCTION

Military vehicles are assigned a Military Load Class (MLC) using a calculation process defined in [1]. The MLC system provides an easy way for the user to determine if a vehicle can safely use gap crossing equipment or not. This system helps to promote safe use of gap crossing equipment and ensures catastrophic failure which may result in injury does not occur.

As concluded in [2], the MLC of a tracked and wheeled vehicle can be affected by small changes in the vehicle's geometry, with changes in length having more of an effect on the MLC than width changes. It was also found in [2] that, for the wheeled vehicle investigated in the study, there existed a specific axle pair for which changes in spacing had the greatest effect on MLC. The longitudinal center of gravity (CG) location was seen as a potential cause for this, due to its proximity to this axle pair and its effect on the location of the vehicle on the bridge for maximum bending moment but had not been explored in detail.

A study was performed to evaluate the influence of changes to the longitudinal center of gravity location on a wheeled vehicle's MLC. The study focuses on the effects of longitudinal CG location changes on the MLC of three different wheeled vehicles. Presented in this paper are the results of this study, as well as a description of the vehicles analyzed in the study and the analytical procedure that was followed.

2. VEHICLES ANALYZED IN STUDY

The study focused on the effects of longitudinal CG location changes on the MLC of three different wheeled vehicles: the Stryker, Palletized Load System (PLS) tractor, and Enhanced Heavy Equipment Transporter System (EHETS) tractor. The effects of geometry changes on the Stryker's MLC were previously evaluated in [2], and this study uses the same base dimensions and weight distribution for the Stryker as in that study. The base dimensions and weight distribution used for the PLS tractor are shown in Tables 1 and 2, respectively. The dimensions are reflective of that used in previous MLC calculations for the vehicle, while the weight distribution is an average of the axle load distributions from ten prior PLS tractor MLC calculations.

Table 1. Base PLS Tractor Dimensions for Study

Width (in)	Axle Spacing (in)			
	1-2	2-3	3-4	4-5
99.1	57.8	137.9	58.8	60

Table 2. PLS Axle Load Distribution for Study

Axle Load Distribution (% of total load)				
1	2	3	4	5
26.20	26.09	16.56	15.68	15.48

The base dimensions and weight distribution used for the EHETS tractor are shown in Tables 3 and 4, respectively. The base dimensions and weight distribution are characteristic of what was used during a previous MLC calculation for the EHETS tractor. An average distribution was not used for this case because the MLC for the tractor has only been calculated once to date.

Table 3. Base EHETS Tractor Dimensions for Study

Width (in)	Axle Spacing (in)		
	1-2	2-3	3-4
101.1	155.5	59.7	59.3

Table 4. EHETS Axle Load Distribution for Study

Axle Load Distribution (% of total load)			
1	2	3	4
47.23	18.24	17.81	16.72

3. ANALYTICAL PROCEDURE

A series of MLC calculations were performed for each vehicle in this study at various weights using the official MLC software mandated per [1]. Calculations were first performed using the base dimensions, then repeated using adjusted axle spacing values. The vehicle width was kept constant throughout, as was the axle load distribution. Deviations from the base axle spacing dimensions of up to 30 inches, and the corresponding longitudinal CG locations resulting from them, were assessed as part of the study. Like [2], the deviation was applied entirely to the spacing between a single axle pair. For each set of axle spacing values, the maximum Rough and Final MLC was recorded over the range of weights considered for each vehicle. The Rough MLC is the MLC resulting from static analysis, while the Final MLC is the MLC, rounded to the nearest whole number, resulting after a correction factor is applied. This correction factor is determined based on a comparison of the width of the actual vehicle and the width of the representative hypothetical vehicle, defined in [1], for the Rough MLC. Once the Rough MLC exceeds MLC 150, then the Rough MLC and Final MLC are equal because there is no hypothetical vehicle above MLC 150 to do a width comparison against without extrapolation. An overview of the MLC calculation procedure formally defined in [1] is provided in [2].

The MLC calculations were carried out at total vehicle weights ranging from 5 tons to the weights given in Table 5, while Table 6 shows the maximum Rough and Final MLCs for each vehicle using the base dimensions. The weights in Table 5 correspond to the weight at which each vehicle's

Final MLC first exceeds 150 using the base dimensions. MLC 150 is the largest MLC for which a hypothetical vehicle exists in [1] for use in design, testing and the MLC calculation process.

Table 5. Maximum Vehicle Weights for Analysis

Vehicle	Weight (tons)
Stryker	87.5
PLS Tractor	112.5
EHETS Tractor	78

Table 6. Maximum MLCs at Base Dimensions

Vehicle	Rough MLC	Final MLC
Stryker	125.6	151
PLS Tractor	123.1	151
EHETS Tractor	124.2	151

The longitudinal CG was calculated for each set of axle spacing values using Equation (1):

$$\mathrm{W}x_{cg} = \left(\textstyle\sum_{i=2}^{n} V_i a_{i-1}\right) \qquad (1)$$

In Equation (1), which represents a moment balance about Axle 1, x_{cg} is the location of the longitudinal CG relative to Axle 1, W is the total vehicle weight, n is the total number of axles of the vehicle, V_i is the axle load at Axle i and a_{i-1} is the distance from Axle i to Axle 1. Solving for x_{cg} results in the following equation for the longitudinal CG:

$$x_{cg} = \frac{1}{W}\left(\textstyle\sum_{i=2}^{n} V_i a_{i-1}\right) \qquad (2)$$

Table 7 provides the longitudinal CG locations, calculated using Equation (2), for the three vehicles assessed in the study at their respective base dimensions and weight distribution. The longitudinal CG falls in the space between Axles 2 and 3 for the Stryker and PLS Tractor, while the longitudinal CG for the EHETS Tractor is in the space between Axles 1 and 2.

Table 7. Base Longitudinal CG Locations

Vehicle	CG Location (in)
Stryker	77.8
PLS Tractor	136.1
EHETS Tractor	112.6

4. RESULTS

4.1. Stryker

It was reported in [2] that, relative to the changes made to the base axle spacing dimensions, changes to the Axle 2-3 spacing resulted in the greatest change to the base value MLC for deviations in the spacing up to 10 inches. This was also observed for deviations beyond 10 inches, up to the 30 inches that was evaluated in this study.

The results differed once the MLCs were evaluated relative to the longitudinal CG location. Figure 1 shows the Rough and Final MLC of the Stryker versus the longitudinal CG location, while Figures 2 and 3 show the Rough and Final MLC plots based on the axle pair whose spacing was changed. Both plots indicate that the MLC of the Stryker generally increases in a non-linear fashion as the CG gets closer to Axle 1. Further examination of Figures 2 and 3 show that, for the same longitudinal CG location, changes to the spacing between Axles 2 and 3 and Axles 3 and 4 result in larger changes to the maximum MLC relative to the base value than do changes to the Axle 1-2 spacing. Changes to the Axle 3-4 spacing also resulted in similar MLC values to that resulting from changes to the Axle 2-3 spacing for the same longitudinal CG location. Except for a couple of cases, the longitudinal CG was generally located in the space between Axles 2 and 3. Therefore, the results indicate that, while changes to the Axle 2-3 spacing resulted in some of the greatest changes in the maximum MLC, the location of the longitudinal CG does not necessarily correspond to the axle pair that results in the greatest change in MLC if changed because changes to the Axle 3-4 spacing may have resulted in similar changes to the maximum MLC.

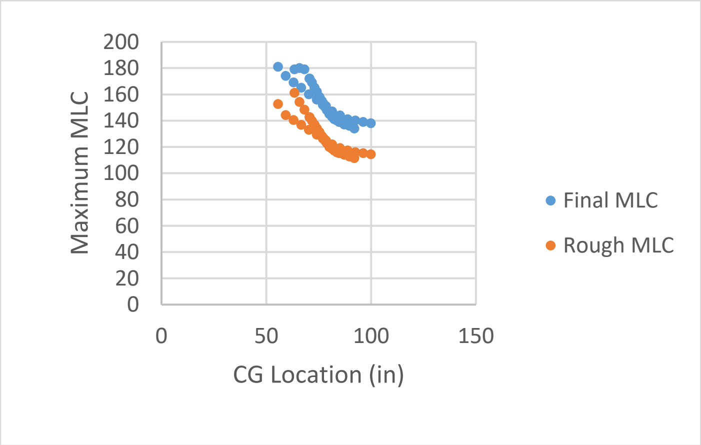

Figure 1: Inverse Relationship between Stryker MLC, Longitudinal CG Location

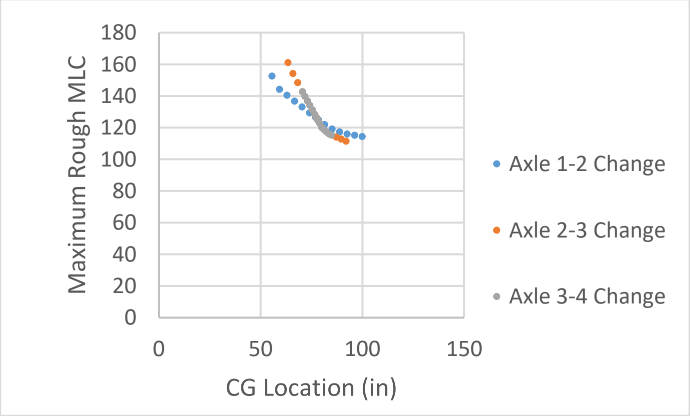

Figure 2: Changes to Axle 2-3, Axle 3-4 Spacing Result in Similar Rough MLC for Same CG Location

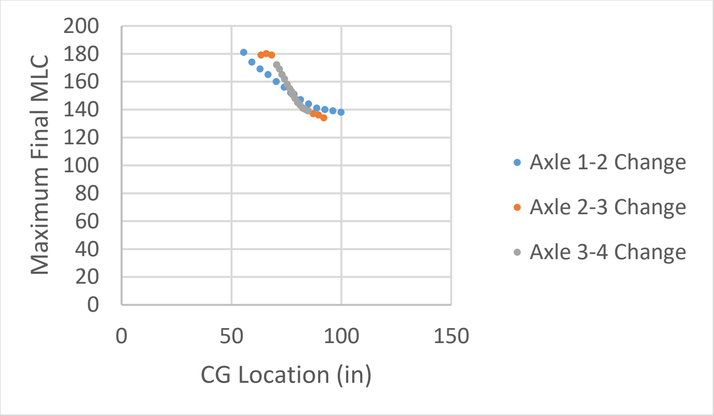

Figure 3: Changes to Axle 2-3, Axle 3-4 Spacing Result in Similar Final MLC for Same CG Location

4.2. PLS Tractor

The longitudinal CG of the PLS tractor fell in the space between Axles 2 and 3 for all sets of modified axle spacing values evaluated in the study. However, as Figure 4 indicates, the maximum deviation from the base (zero deviation) maximum MLC value resulted from changes to the spacing between Axles 1 and 2, with the deviations being more substantial for decreases in spacing greater than 10 inches. The maximum MLC deviation from the base values was approximately 93 for the Rough MLC and 65 for the Final MLC. Both maximum deviations occurred due to a decrease in the Axle 1-2 spacing of 30 inches. In comparison, the maximum MLC deviated from the base value by no more than 14 when the spacings of the other axle pairs were changed.

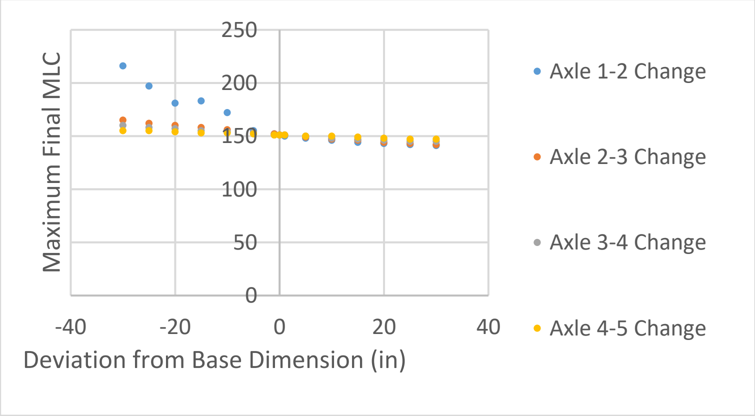

Figure 4: Change in Axle 1-2 Spacing Results in Greatest Change in PLS MLC Relative to Base Dimensions

Figures 5 and 6 show the maximum Rough and Final MLC, respectively, versus the longitudinal CG location based on the axle pair whose spacing was changed. As the figures indicate, a relationship does exist between the longitudinal CG location and maximum MLC, as the MLC generally decreased in a non-linear fashion the further the longitudinal CG moves from Axle 1 of the vehicle. The non-linear change in MLC with respect to the longitudinal CG location is similar to what was observed for the Stryker. The figures also highlight the substantial deviation that occurs as the Axle 1-2 spacing is decreased further and further. Other than 5 points on the plot, the MLC did not deviate much at each CG location due to change in spacing between axle pairs.

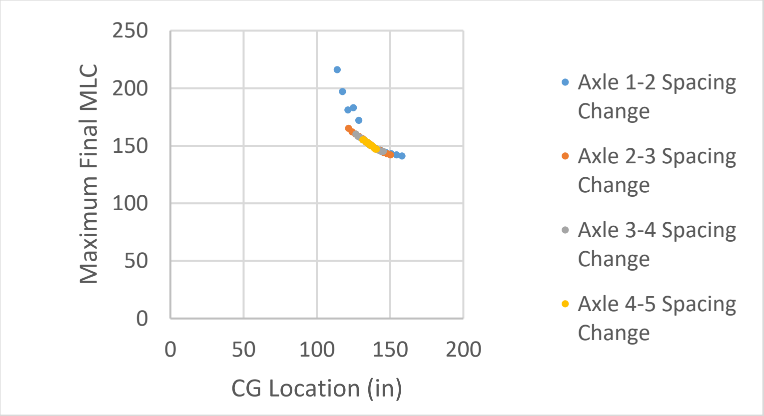

Figure 5: Change in Axle 1-2 Spacing Results in Greatest Change in PLS MLC Relative to Base Dimensions

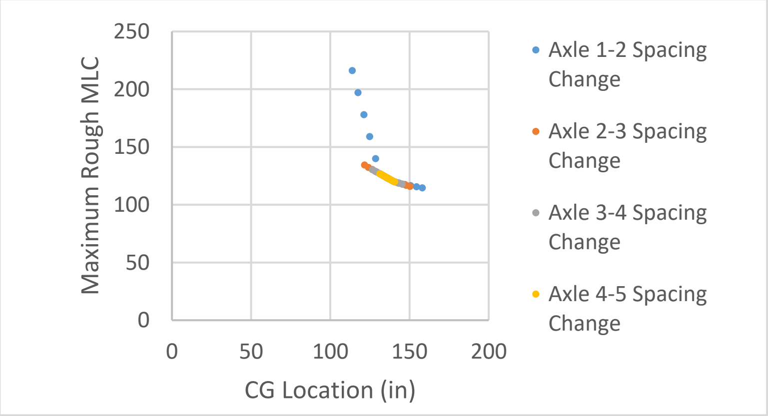

Figure 6: Change in Axle 1-2 Spacing Results in Greatest Change in PLS MLC Relative to Base Dimensions

4.3. EHETS Tractor

For the EHETS tractor, the longitudinal CG was in the space between Axles 1 and 2 for all modified axle spacing sets resulting from deviations up to 30 inches. The EHETS tractor MLC was generally found to be insensitive to changes to the longitudinal CG locations resulting from axle spacing deviations up to 30 inches. For all deviations, the Rough and Final MLC came out to 124.19 and 151, respectively. Thus, the Rough and Final MLC were constant with respect to the longitudinal CG locations initially calculated for this study. Further examination indicated that increases in spacing beyond 30 inches resulted in no change to the maximum MLC relative to the base value. However, a minimum reduction in the Axle 1-2 spacing of 92 inches was required before the maximum MLC changed relative to the base value. Changes to the Axle 2-3 and Axle 3-4 spacing did not result in any changes to the MLC of the vehicle, regardless of how much the spacing was changed. Therefore, it is concluded that the MLC of the EHETS is insensitive to changes to the longitudinal CG location resulting from changes to the Axle 2-3 and Axle 3-4 spacing.

Additional calculations were performed to examine how the maximum MLC behaves with respect to changes to the longitudinal CG location due to Axle 1-2 spacing deviations of 92 inches and greater. The results of the assessment are shown in Figure 7, while Figure 8 focused on the part of the Figure 7 that is not constant. At these extreme deviations, the longitudinal CG fell between Axles 2 and 3, thus serving as additional evidence that the longitudinal CG location does not correlate to the axle pair that results in the greatest MLC change if its spacing is changed. Like the PLS Tractor and Stryker, Figure 8 shows that the MLC is inversely related to the longitudinal CG location. However, the relationship between maximum MLC and longitudinal CG location appears to be more linear than it was for the PLS or Stryker.

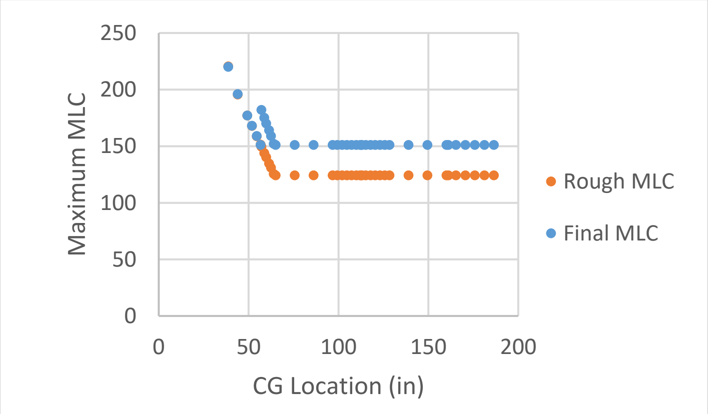

Figure 7: CG Locations of 64 inches and Lower Result in MLC Changes for the EHETS Tractor

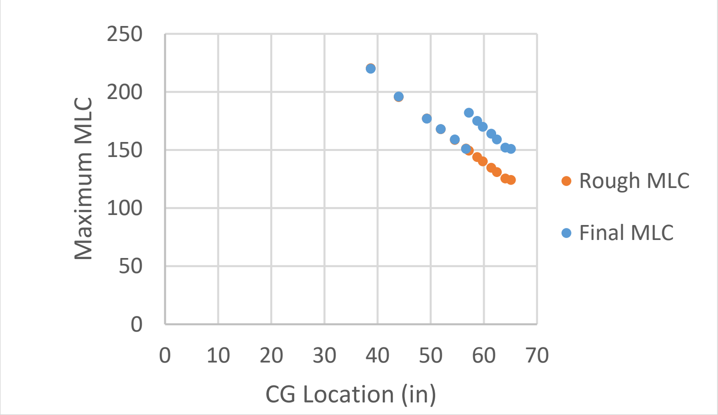

Figure 8: EHETS MLC is Inversely Related to the Longitudinal CG Location at Locations up to 64 Inches

5. DISCUSSION

Overall, the results of the study indicate that a relationship exists between a vehicle's longitudinal CG location and its maximum MLC. An inverse relationship was observed between the longitudinal CG location and the Rough and Final MLC for all the vehicles evaluated in this study. The nature of the relationship between the longitudinal CG location and MLC appears to be dependent on the vehicle being evaluated. The Stryker and PLS exhibited a non-linear relationship between the two, while the relationship for the EHETS appears to be more linear. The axle pair whose spacing is adjusted to change the longitudinal CG location also had an effect in the results of some of the vehicles, namely the Stryker, based on the change of slope observed in the plots in

Figures 2 and 3, and EHETS, whose MLC remained constant regardless of the change made to the spacing between some axle pairs.

The study does indicate that the longitudinal CG location is not a general indicator of the axle pair whose change in spacing has the greatest effect on its MLC. None of the three vehicles evaluated in this study had its greatest change in the maximum MLC definitively resulting from a change in the spacing between the axles that the longitudinal CG fell between. This, along with the differences in the results for the three vehicles evaluated in the study, means that wheeled military vehicles need to be evaluated on a case-by-case basis to determine the axle spacing change that will result in the greatest change in MLC.

Further evaluation of the results for the PLS Tractor reveals an interesting observation. It is noted that changes to the Axle 1-2 spacing resulted in the greatest MLC change from the base value for the same longitudinal CG location, even though the longitudinal CG mainly remained in the space between Axles 2 and 3. Based on the weight distribution in Table 2, Axles 1 and 2 carry more load than the remaining three axles. Therefore, the results indicate that the MLC is most sensitive to geometry changes that affect the axles carrying the most load. This seems to be more significant when the vehicle weight is not evenly distributed among the axles. The Stryker, whose axle load distribution was more balanced than the PLS or EHETS tractors, did not exhibit similar behavior. For the Stryker, changes to the Axle 1-2 spacing resulted in smaller MLC changes for the same longitudinal CG location than did changes to the Axle 2-3 or Axle 3-4 spacing, even though Axles 1 and 2 carried the most load.

The sensitivity of the MLC to changes affecting the spacing of the heaviest axle was also apparent when evaluating the results for the EHETS Tractor. As Table 4 shows, almost 50 percent of the vehicle weight is carried by Axle 1. For this vehicle, the maximum MLC only changed from the base value when the longitudinal CG location changed due to adjustments to the Axle 1-2 spacing. Longitudinal CG locations corresponding to extreme changes to the Axle 2-3 and Axle 3-4 spacing, such as reducing the spacing to 1 inch, resulted in no change in the MLC from the base value. This indicates that, for vehicles where one axle is carrying a much higher amount of weight than the other axles, the MLC is only sensitive to geometry changes affecting the heaviest axle.

6. CONCLUSION

A study was performed to assess the influence of the longitudinal CG location on a wheeled vehicle's MLC. The study focused on the effects of changes to the longitudinal CG location, resulting from changes to the spacing between different axle pairs, on the MLC of the Stryker, PLS Tractor, and EHETS Tractor. The study found that the longitudinal CG location does not provide a general indication of where to change the vehicle length to have the greatest effect on its MLC. However, a relationship does exist between the longitudinal CG location and a vehicle's maximum MLC. While an inverse relationship was found for all vehicles assessed in the study, the specific relationship depended on the vehicle and the axle pair whose spacing was changed to adjust the CG location. The axle load distribution also was found to play a role in the effect of the longitudinal CG location on a vehicle's maximum MLC. Geometry changes specifically affecting the heaviest axle had more of an effect on the vehicle's maximum MLC if the vehicle had an uneven distribution. Ultimately wheeled vehicles should be evaluated on a case-by-case basis to determine what axle pair spacing to change to have the greatest effect on its MLC.

7. REFERENCES

[1]STANAG 2021 (8th edition) – AEP- 3.12.1.5 (edition A, version 1), NATO standard, “Military load classification of bridges, ferries, rafts and vehicles”, NATO Standardization Office (NSO), 2017

[2]B. Sia, “A Study on the Effect of Geometry Changes on a Vehicle’s Military Load Class,” Proceedings of the Ground Vehicle Systems Engineering and Technology Symposium, pages 16-18, 2022