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Improving Winter Traction for Vehicles in Northern Operations

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ABSTRACT

As part of the campaign to increase readiness in northern regions, a near commercial-off-the-shelf (COTS) solution was identified for the High Mobility Multipurpose Wheeled Vehicle (HMMWV); and used to assess the suitability of commercially available winter tires for operational deployment. Initial performance evaluations conducted during the winters of 2020 and 2021 demonstrated and quantified significant improvements to traction and handling on a variety of winter surfaces. User feedback from United States Army Alaska (USARAK) Soldiers confirmed these results in an operational environment.

Results of this study provide new winter tire specifications for the Army and justify the procurement of a HMMWV winter tire for improved safety and capability for US Soldier and vehicle fleet needs. The data and Soldier evaluations support attaining a National Stock Number (NSN) and provide data to develop models of winter vehicle performance that include the impact of winter tires and chains. This work also paves the way for future development and procurement of winter tires for vehicles where COTS solutions are unavailable. The motivation is to provide Soldiers with state-of-the-art winter tires to increase safety, capability, and operational compatibility with North Atlantic Treaty Organization (NATO) partners in the European Theater of Operations, and mobility superiority in all environments.

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1. INTRODUCTION AND BACKGROUND

1.1. OBJECTIVE

In 2019, a collaborative effort between the several Army organizations and industry was launched to develop new Army specifications for winter tires, and enable procurement of commercial-off-the-shelf (COTS) winter tires for the High Mobility Multipurpose Wheeled Vehicle (HMMWV) family of Light Tactical Vehicles (LTV), and at the same time to collect data that can be used to improve winter mobility modeling algorithms to include the impacts of winter tires and chains.

This procurement effort for winter tires for the HMMWV family of light tactical vehicles paves the way for future improvements to winter traction on other Army vehicles expected to operate in northern environments.

1.2. THE IMPORTANCE OF WINTER AND ARCTIC OPERATIONS

Historically, winter warfare has been an opportunity for those with knowledge and experience. This was recognized as early as the 4th or 5th century BC by Tzu Sun's *The Art of War* "darkness and winter are friends to the tough and skillful" as reported in the historical treatise *On Winter Warfare* (Swinzow, 1993) [1], which also states "in cold climates the more prepared side will deliberately select winter for the decisive battle".

Northern environments includes polar, sub-arctic, warm continental, and temperate steppe climate types with cold, snowy winters and mean temperature during the coldest month below 32°F (0°C). For full descriptions of global military operating environments and definitions of specific regions, see the recently updated Army Regulation 70-38 (US Army, 2020) [2].

Currently, the Arctic is of specific interest due to a warming climate and reduced Arctic sea ice cover resulting in the Arctic reopening to recreation and commerce. This has led to increased economic interest, political posturing and potential conflict regarding control and access. The DoD has realized the strategic importance of the Arctic for both homeland security and defense. Specifically, the *DoD Arctic Strategy* (2019) [3] states:

"The U.S. Arctic deterrent will require agile, capable, and expeditionary forces with the ability to flexibly project power into and operate within the region, as the Joint Force must be able to do elsewhere globally."

"DoD will work to ensure that forces deployed within Arctic areas of operation employ ground mobility assets capable of sustained operations in extreme cold weather, across all forms of terrain that may be encountered on a year-round basis."

The most recent strategic document stating the importance of the Arctic specifically for the US Army is the *Army Arctic Strategy, Regaining Arctic Dominance*, Jan. 2021 [4], which directs the US Army to "Explore opportunities and capabilities which improve mobility in an Arctic environment".

The United States (US) military has adversaries with well-known winter capabilities in the far north [5]. While winter tires are basic requirements for safe and efficient wheeled vehicle operations in northern environments, winter tires are basically unavailable for the current vehicle fleet. This can cause issues when US DoD equipment cannot meet in-country requirements for winter tires in northern North Atlantic Treaty Organization (NATO) countries and therefore becoming disabled or unreliable during joint winter exercises.

The US has been focused on desert theaters of war for the last three decades, therefore Soldiers in northern environments are often forced to operate with tires optimized for summer or desert environments because those are the only tires available. Additionally, the US Department of Defense (DoD) tire standards were adopted in the 1970s and tire rubber compounds, structure and tread design have improved significantly over the last 50 years. New winter tire designs do not meet the outdated requirements and are not readily available to our Soldiers. Lastly, of primary significance is that very few COTS winter tires are available in sizes needed for military vehicles.

1.3. WHY A WINTER TIRE FOR THE HMMWV?

The US recently launched a large scale effort to broaden its presence in Arctic and Sub-arctic regions and increase readiness for Arctic warfare. As part of this effort various groups within the DoD are researching improvements to military equipment which supports year-round projection of forces in cold regions.

While several new vehicles are in active development, none are intended as immediate full fleet replacements for the HMMWV family of LTVs (Figure 1). With over 200,000 HMMWV LTVs in the US inventory, 50,000 are projected to remain in service after vehicles such as the Joint Light Tactical Vehicle (JLTV) are fielded. The HMMWV family has been in continuous operation since 1983, but little has been done to improve its capability on winter terrain.

Figure 1: The instrumented M1097 HMMWV on snowy roads in northern New Hampshire.

Conversely, in the late 1990s, the commercial vehicle market began adopting the Three Peak Mountain Snowflake (3PMSF) rating to identify winter capable tires. Previous to the 3PMSF rating, tires considered suitable for the winter terrain were rated Mud and Snow (M+S). M+S is typically considered a three season tire, for occasional use in light snow. The M+S tires available for the HMMWV do not feature factory siping, which is a proven method to increase grip over wet, icy, or snowy surfaces. Siping is a common feature across consumer winter tires. Tires marked with the 3PMSF pictograph indicate the tire meets specific snow grip requirements using standard testing methods, whereas the M+S marking is determined by the tire manufacturer and does not have an industry test standard for performance levels in snow.

Currently the US Army fields only M+S rated HMMWV tires, all of which fit the same terrain parameters and are interchangeable. Though there are multiple load ranges, there are only two tires currently available for the HMMWV and both are intended for driving over paved and off-road conditions such as dirt, rocks, and mud, where a knobby tread pattern is particularly advantageous. There is no specific Army-wide requirement to run a winter rated tire on the HMMWV, nor is a 3PMSF tire currently available to military units through procurement via a national stock number (NSN), but 3PMSF is increasingly mandated in northern European countries.

For winter operations, the HMMWV Technical Manual dictates equipping the standard tires with chains and lowering tire pressure to a specific value for each variant and load range. However, mounting chains or dropping tire pressures creates major operational disadvantages, causing delays and presenting dangerous situations for Soldiers during tactical maneuvers. Speed limits are severely limited by using either Mud, Sand and Snow (MSS) tire pressures (limited to 25 mph), or chains (limited to 10 mph). Installing tire chains takes a considerable amount of time, forcing the vehicle to stop and Soldiers to exit the vehicle to complete the installation. For experienced users, chain installation takes around 20 minutes. If Soldiers are unfamiliar with the chains, this timespan can quickly multiply, causing significant delays in operations, and risking continued exposure of the crew. Tire chains must be rechecked for fit after the first mile travelled. Loose chains may impact the body and frame of the vehicle or potentially slip off, and they cannot be used on paved roads without causing road damage. Ride quality is substantially diminished. Lastly, the 10 mph speed limit when operating a HMMWV with tire chains reduces throughput and puts Soldiers in harm's way.

Unlike the standard tire and chain combo, a winter tire set provides excellent vehicle performance on paved and unsurfaced roads in addition to snow and ice capability. And most importantly, the HMMWV winter tire is an all season tire and can be used for the entire duration of operations including summer, while vastly improving safety for Soldiers operating or training in winter environments. Potential fielding locales include European Command (EUCOM), Northern Command (NORTHCOM) and especially Alaska Command (ALCOM), Indo-Pacific Command (INDOPACOM) specifically allied Forces in Japan and Korea, and global Army and Marine Corps strategic Prepositioned Stock (PS) reserves.

2. APPROACH

2.1. Drafting Winter Tire Specifications

The first task was to create a specification for military winter tires. The standard tire for the HMMWV was designed before the adoption of the new snow and ice standards in the commercial market, and the existing military tire standards were not particularly applicable to a modern winter tire. A commercial tire is vigorously tested in winter conditions so as to achieve the Three Peak Mountain Snowflake rating. The military needs, however, are quite different than for commercial on-road vehicles, so new assessment specifications were needed.

2.2. Preliminary Demonstration of Capabilities

An informal demonstration of the capabilities of a 3PMSF rated winter tire was performed at the Keweenaw Research Center in Calumet, Michigan in February 2020. Michelin and their contractors staged the winter tire demonstration with input and attendance from Army employees from PEO CS& CSS (Program Executive Office, Combat Systems and Combat Service Support), ERDC-CRREL (Engineering Research and Development Center – Cold Regions Research and Engineering Laboratory), US Army Combat Capabilities Development Command (DEVCOM) GVSC (Ground Vehicle Systems Center) Engineering Support (ES) - Tires, and JLTV Safety. Qualitative feedback of the winter tire capabilities was decidedly positive, and initial quantitative testing results from this demonstration showed 67% improvement in traction over the standard tire. The increase in slope climbing capabilities alone would increase maneuverable terrain area in Arctic locations by over 10%. The result of this event provided the basis for creating Army winter tire specifications and the follow-on prototype winter tire set distribution for preliminary evaluation.

2.3. Experiments at CRREL

Located in Hanover, NH, CRREL is one of the seven ERDC labs within the US Army Corps of Engineers. CRREL Force Projection & Sustainment Branch includes a mobility research team with experience in experimental and modeling research and development for Army vehicles operating in winter environments.

CRREL owns a M1097R1 HMMWV (6716 lb) that was previously instrumented for acquiring 6-dof (6 degrees of freedom; 3 force vectors and 3 moment vectors) wheel load, wheel speed, driver inputs, and acceleration and rate sensors at the vehicle center of gravity for vehicle dynamics testing as reported by Sopher [6]. For these experiments, the instrumented wheels were removed to accommodate the winter tire 17 inch rims. Hall-effect sensors were added to collect wheel speeds for slip calculations, and test methods changed from individual wheel force measurements to full vehicle testing (Figures 1 and 2). Accordingly, the CRREL Instrumented HMMWV was equipped with the following sensors:

i. Inertial Measurement Unit (IMU) to acquire pitch, roll, yaw, longitudinal and lateral acceleration.
ii. External load cell to measure hard surface rolling resistance, motion resistance and drawbar pull in various winter conditions.
iii. Global positioning system (GPS) for speed and position.
iv. Fifth wheel for true vehicle speed.
v. Throttle, brake, and steering position sensors.
vi. Individual wheel speed Hall effect sensors.

Figure 2: Drawbar Pull testing in 20 cm of fresh snow, Jan 2021.

The CRREL Instrumented HMMWV has front and rear axle locks which prevent wheels from spinning at different speeds. All tests were completed in the fully locked configuration. Apart from the installation of the data acquisition system, there are no modifications to the vehicle and it is in the same configuration as when refurbished in 2008.

Testing was performed at the CRREL site in Hanover, NH and at the nearby Team O'Neil Rally School located in the White Mountains near Mt. Washington in Dalton, NH from January to March 2021. Performing all tests within NH was extremely beneficial during the COVID 19 travel restrictions. The Team O'Neil test sites provides 583 acres of northern mountainous terrain with 6 miles of staged rally courses and optimal weather for testing on unpacked and packed snow surfaces, including skid pads on flat and unpaved winter surfaces. Experiments consisted of standard, chained and winter tire configurations and included 1) motion resistance and draw-bar pull testing on multiple winter surfaces; 2) specific vehicle dynamics testing and a traverse comparison on packed snowy road condition; and 3) general use, performance and maintenance tracking.

Straight-line experiments performed included Hard Surface Rolling Resistance (HSRR), Motion Resistance (MR), Drawbar Pull (DBP), and acceleration and braking on a variety of winter surfaces. Additional testing to capture lateral stability occurred on a packed snow and ice surface similar to a packed snowy road. The dynamic testing included slalom, circle breakout (CBO) and traverses consisting of slopes and corners. Tests were designed to assess longitudinal and lateral traction and general maneuverability of the HMMWV on winter surfaces with standard and winter tires.

2.4. Soldier Touchpoint Surveys and Qualitative Testing in Alaska

A survey was distributed to the USARAK Soldiers of the 17th CSSB (Combat Sustainment Support Battalion) to collect hands-on information from units that will benefit from having winter tires. This unit provides year-round logistics support in Alaska between Joint Base Elmendorf-Richardson in Anchorage and Fort Wainwright in Fairbanks, a round trip of 720 miles. The survey information collected included specifying the mission profile (Highway, Gravel, Trails/Cross Country), locations driven, dates, road surface conditions (Icy, Dry, Wet, Packed Snow, Slush, Other), the specific vehicle, tire pressures, etc., and a rating from 1 (worst) to 10 (best) for performance measures such as traction, cornering, braking, ride comfort, tread life, durability and if chains were used. The drivers included Soldiers with various degrees of experience, ranging from Privates on their first enlistment to Master Driver-certified Non-Commissioned Officers.

Data collection, driver interviews and an after action review occurred during March 2021. The engineering team from PM-JLTV, GVSC, CRREL and Michelin met with the USARAK Soldiers for feedback. During that time, Michelin also performed a series of qualitative testing using similar HMMWVs with and without the winter tires. Tests performed included braking and accelerations and sinuous maneuvers in fresh snow (Figure 3), packed snow, and plowed road surfaces.

User surveys were also distributed to the CRREL engineers to use during the tire break-in, driving to test sites, and during testing in NH from January to March 2021.

Figure 3: Vehicle maneuvers in deep snow in Alaska, March 2021.

3. RESULTS

3.1. New Specifications for Winter Tires

Key parameters for a winter tire for the military would include not only excellent winter road performance, as designated by the alpine (3PMSF) marking for winter performance, but it must also perform well in a wide variety of environments with minimal degradation, including off-road, unpaved roads and trails, and various surfaces conditions in all seasons including warm and hot weather. Table 1 gives some highlights of the proposed winter tire specifications. The additional specification for all season performance requires that the tire maintains satisfactory performance (braking and handling) in warmer temperatures (above 80°F). The full set of draft specifications is currently under consideration by the GVSC Standardization Team.

Table 1. Select specifications for winter tires for the HMMWV.

Acceleration - Packed Snow	The HMMWV at Gross Vehicle Weight (GVW) with winter tires shall have 20% or greater acceleration than the reference tire on packed snow
Deceleration - Packed Snow	The HMMWV at GVW with winter tires shall have 35% or greater deceleration than the reference tire on packed snow
Acceleration - Ice	The HMMWV at GVW with winter tires shall have 20% or greater acceleration than the reference tire on ice
Deceleration - Ice	The HMMWV at GVW with winter tires shall have 35% or greater deceleration than the reference tire on ice
Acceleration - Unprepared Snow	The HMMWV at GVW with winter tires shall have 25% or greater acceleration than the reference tire in unprepared snow.
Hill Climb / Gradeability - Snow	The HMMWV at GVW with winter tires shall successfully ascend a longitudinal slope of 25% or higher grade on a packed snow surface
Hill Climb / Gradeability - Ice	The HMMWV at GVW with winter tires shall successfully ascend a longitudinal slope of 20% or higher grade on an ice surface
Subjective Handling - Snow	The HMMWV at GVW with winter tires shall improve lap times by 10 % or more (reduced lap time) on subjective handling course on snow surface when compared to the reference tire
Lateral Traction - Packed Snow	The HMMWV at GVW with winter tires in pure fitment when tested in accordance with SAE J2014 [6] Steady State Dynamic Stability shall achieve a lateral acceleration of 15% or greater than the reference tire on packed snow surface without departure from constant radius course (T=O).
Low Temperature Operation	The HMMWV shall have winter tires that are capable for operation at temperatures of -60°F (T=O).

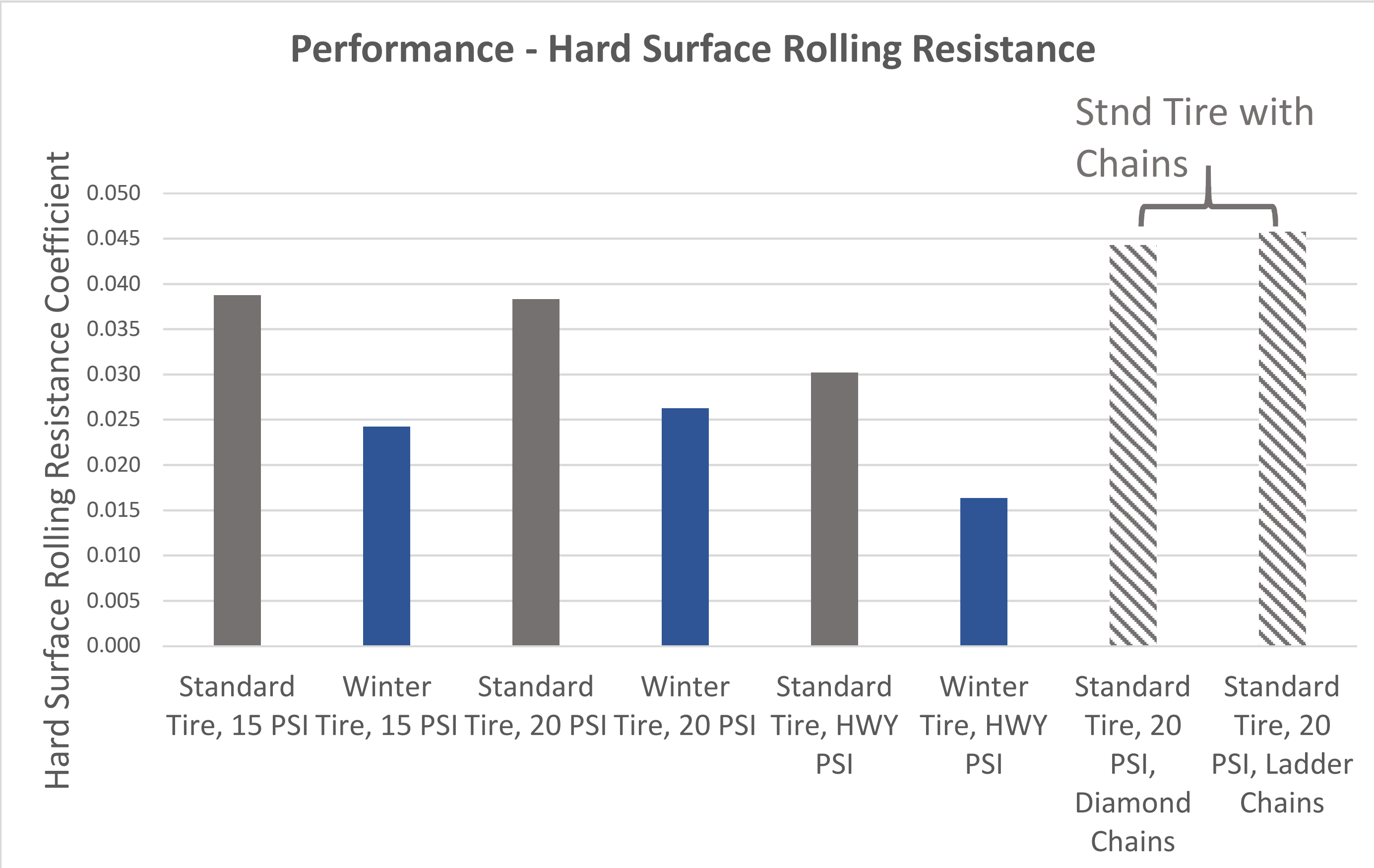

Figure 4: Hard surface rolling resistance of the standard tire (gray) and winter tire (blue) showing the winter tires having consistently lower rolling resistance. For comparison, the rolling resistance of the standard tire with chains is shown in patterned bars.

3.2. Performance measurements by ERDC-CRREL

3.2.1 Hard Surface Rolling Resistance and Motion Resistance

Hard surface rolling resistance measurements were performed on a flat asphalt surface at temperatures within five degrees of the snow test temperatures. The winter tires consistently offer lower rolling resistance, as shown in Figure 4. This is likely because of their modern materials and design primarily for on-road, whereas the standard HMMWV tire has a knobby tread pattern and rounded shoulders more typical of off-road tires.

The decreased rolling resistance translates directly to fuel savings over the standard tire. This energy savings supports Executive Order 14008 and the Secretary of Defense response memo stating to consider climate change in decision making, and increase platform efficiency [7,8].

The hard surface rolling resistance values are also used to estimate that portion of the motion resistance that is due to terrain (snow) deformation, which can be substantial on an undisturbed snow cover. Due to COVID 19 and shipping delays, however, most testing was performed on packed snow.

3.2.2 Longitudinal Traction

Longitudinal traction was measured using a constant speed, continuous slip draw-bar pull test, as specified in SAE J2014 [9], which is designed to capture a full traction slip curve similar to the technique used for single tire traction testing [10]. Different surfaces and tire and chain combinations were measured. The motion resistance for these same combinations was measured on the same winter surfaces so that a gross traction could be reported. The gross tractive force was converted to a coefficient by dividing by the total static vehicle weight. Three to five tests were usually averaged to report a value for each tire and surface combination.

A summary of select test combinations are shown in Figure 5, indicating a 93% improvement in longitudinal gross traction of the winter tire over the standard HMMWV tire. While chains can improve traction even more, the disadvantage of mounting the chains, along with reduced driving speed and increased maintenance and checking of chains would severely reduce throughput.

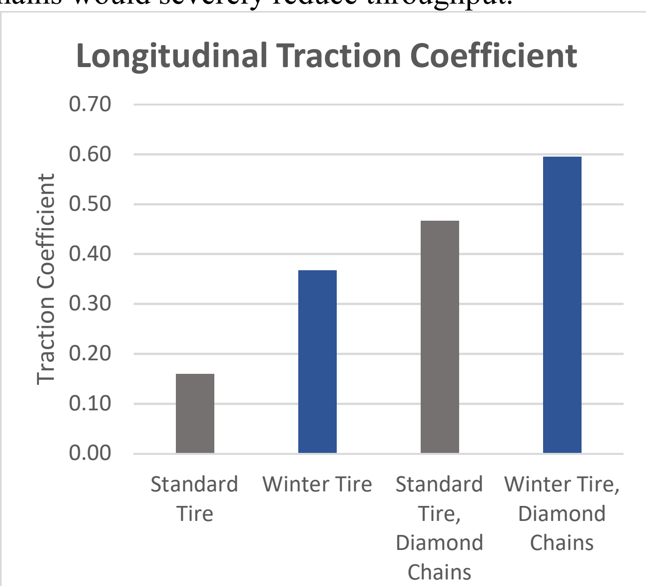

Figure 5: Longitudinal gross traction coefficient comparison between the standard HMMWV tire and the winter tire, with and without chains on a medium packed snow surface (based on ASTM, 2020 [10]).

Providing grip for as long as possible during a slip event is extremely advantageous for vehicle handling. Therefore, wheel and vehicle speeds were used to generate characteristic traction coefficient (mu) versus slip curves (Figure 6). For the winter tire mu-slip curves, traction is gained over a wide range of wheel slip. The importance of this to the driver is that once the tires begin to slip, you do not immediately lose or reduce traction and therefore can maintain vehicle control. The typical traction curve shape for the standard tire shows either a level traction or a decrease in traction after a peak value, which is maximum at a low value of slip, reducing the time to react during an accident avoidance maneuver or accidental engagement of slip.

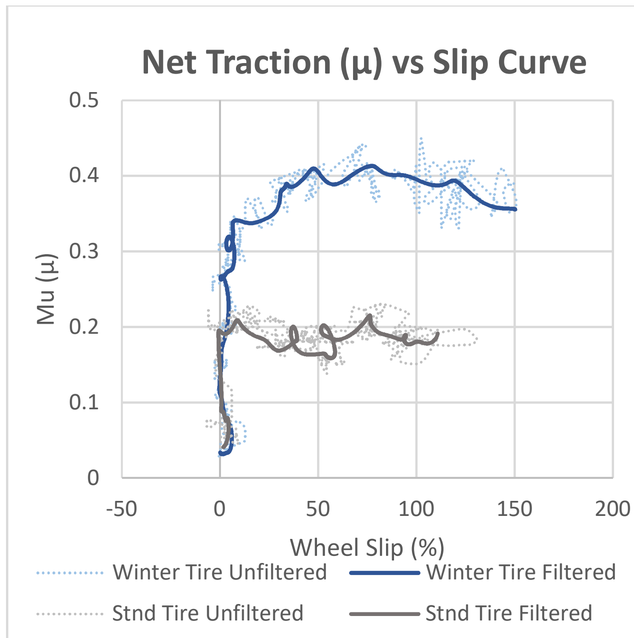

Figure 6: Example typical curve shapes for net traction (Draw Bar Pull) coefficient with wheel slip. The Winter Tire shows increased traction over a range of wheel slip, allowing for greater vehicle control.

3.2.3 Lateral Traction for Cornering

Lateral traction is an important metric when considering handling of a vehicle. A vehicle with good lateral traction holds onto the road or snow surface during turning maneuvers, remaining in control. An estimate of lateral traction and control is calculated from the maximum lateral acceleration achieved during turning maneuvers. We performed two tests to capture the limit of lateral traction; one was a slalom test where speed was gradually increased until the vehicle slid laterally (Figure 7), and the other was a circle breakout test where the speed is gradually increased until the vehicle slides laterally. Tests were conducted several times at each speed and the results averaged.

Results from the slalom test are shown in Figure 8. The top speed where the driver was unable to prevent sliding was at 25 mph, therefore this is the test that gives the best comparison of the maximum lateral traction for the two tires since they were both at the performance limit. The winter tire was able to provide 43% more lateral traction in this test.

Figure 7: HMMWV testing of lateral acceleration during the slalom test on packed snow and ice.

The second cornering test consisted of constant turning in a 20 meter radius circle with steadily increasing speed until the vehicle slides laterally. This is commonly referred to as the circle break out (CBO) test. The goal of this test is to measure top speed and the limit of lateral acceleration before the vehicle begins to slide. Again, the vehicle on standard tires slid out sooner and was unable to corner with as much force as when using the winter tires (Figure 9).

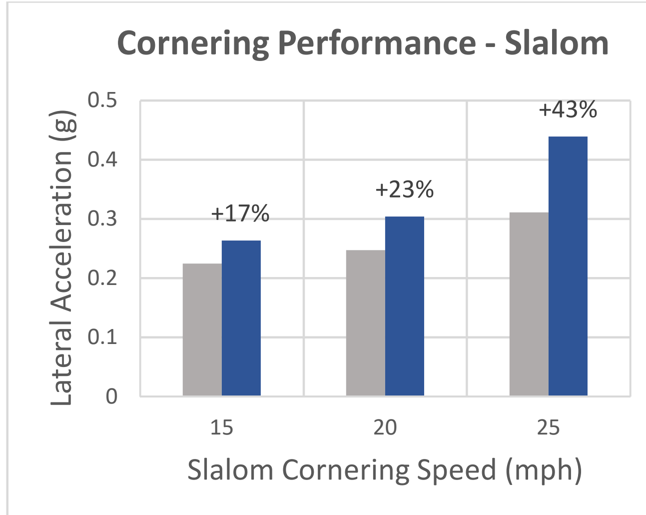

Figure 8: Lateral acceleration of the HMMWV for each speed of the test. Both tires were at their limit and slid during the 25 mph test showing that the winter tire can achieve 43% more lateral acceleration (traction). Gray is the standard tire, Blue is the winter tire.

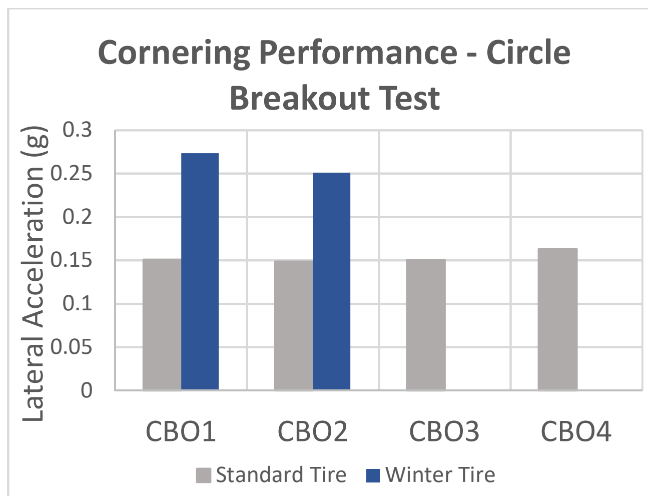

Figure 9: Peak lateral acceleration from the circle breakout (CBO) test showing the increase lateral grip performance of the winter tire. Gray is the standard tire (4 tests), Blue is the winter tire (2 tests).

Note that for consistency, all tests were performed with locked differentials (in 4LO). This could impact test results, especially for the dynamic lateral traction testing. Evaluation of the impacts of this is a topic for future study given the renewed interest in operating in these conditions.

Summarizing, the winter tires show a substantial increase in longitudinal and lateral traction (93% and 43% improvement respectively). Drivers noted that both the slalom and circle tests were much easier to complete and control using the winter tire. This was later proved out during the traverses on the snowy roads which contained curves, tight corners and various slopes. During the traverses with the standard tire the vehicle slid into snow berms, sometimes twice during the same traverse, whereas the same vehicle with winter tires was easily controlled throughout the traverse event.

3.3. Soldier Touchpoint in Alaska and Driver Assessments in New Hampshire

Soldier testimonials during testing at USARAK were universally positive. Every Soldier who had the opportunity to drive the HMMWV with the winter tires stated that they would prefer using them over the standard tires, and felt more confident driving and controlling the vehicle when using the winter tires. Multiple comments highlighted the improved grip, as noticed during acceleration, braking, and turning when operating the vehicle on snow.

The CRREL surveys also noted increased traction, maneuverability and braking capability when using the winter tires during driving. The driver experience for this group ranged from a conventional commuter to an amateur race driver and covered approximately 310 miles on secondary roads, snow covered unpaved roads and snow and ice covered test sites. The performance improvement was noted for both low-speed testing and for the higher-speed maneuvers.

4. BENEFITS

The winter tire showed clear improvements to traction and handling of the HMMWV in winter conditions. An Army approved winter tire will increase the capability of the HMMWV LTV in snow conditions without severely degrading performance on other terrain types, thus could be used all year long. While the winter tire does not provide as much traction as a chained tire, chains are 1) time consuming to install, 2) limited to a top speed of 10 mph, and 3) must be checked at a stop after the first mile. Therefore, using chains has the strong disadvantage of decreasing operational speed and convoy throughput, as well as forcing a tactical halt to movement, all putting Soldiers in harm's way.

Specifically, benefits related to the improved traction and handling from winter tires include:

- Increased Soldier safety, decrease traffic accidents, decrease vehicle damage due to sliding
- Improved throughput for winter logistics
- Increases fuel economy through reduced rolling resistance
- Compatibility with in-country laws of NATO countries requiring winter tire use during winter months
- Increased fleet readiness for cold climate and arctic domains
- Supports DoD and Army Arctic Strategy for an agile and capable force with improved mobility in the Arctic

5. FUTURE NEEDS

The prototype winter tire sets will be used routinely in Alaska throughout the rest of FY21 and beyond, including all-season logistics and transport missions and summer operations. Official durability and Society of Automotive Engineers (SAE) J2014 [9] testing is currently being conducted by the Nevada Automotive Test Center.

The procurement process for winter tires for the HMMWV family of light tactical vehicles will pave the way for future improvements to winter traction on other Army vehicles expected to operate in northern environments. New winter tire specifications for the HMMWV will serve as a model for updating other vehicles for operations in cold regions. Requirements and funding would need to be formalized to fully support the Arctic Strategy and equip the HMMWV and other tactical vehicles with winter tire kits.

The data collected is useful to upgrade winter mobility models to include the impacts of winter tires and chains. Current cold regions mobility models were based on vehicle testing from the 1990s to capture the behavior on snow and ice, freezing and thawing ground [11,12,13]. We have recently begun work to upgrade and validate these models for modern and over-snow vehicles, more accurately distribute the seasonal terrain properties and mobility predictions within a geospatial framework, and to include the highly organic peat and muskeg terrains of the far north [14,15,16].

Future needs include expanding our knowledge of terrain types and conditions common to the extreme cold weather environments of the far north, including arctic snow types, ice bridges and ice covered waterways, tundra, muskeg, and mountainous terrain. Furthermore, climate changes impact ground freezing and thawing, and the shoulder seasons (Rasputitsa) are changing in both their geospatial range and timing of occurrence, frequency and duration [17]. Lastly, new models of winter and seasonal terrain and consequent mobility must be incorporated into the next generation of mobility models [18,19].

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8. LIST OF ACRONYMS

CCDC	US Army Combat Capabilities Development Command
CFTs	Cross Functional Teams
CNN	Cable News Network
COTS	Commercial-Off-The-Shelf
COVID 19	COrono VIrus Disease 2019
CRREL	Cold Regions Research and Engineering Laboratory
CSSB	Combat Sustainment Support Battalion
DBP	Draw bar pull
DEVCOM	US Army Combat Capabilities DEVelopment COMmand
DoD	Department of Defense
dof	degree of freedom
ERDC	Engineering Research and Development Center
ES	Engineering Systems
EUCOM	European Command
FY	Fiscal Year
GPS	Global Positioning System
GVSC	Ground Vehicle Systems Center
GVW	Gross Vehicle Weight
HMMWV	High Mobility Multipurpose Wheeled Vehicle
HSRR	Hard Surface Rolling Resistance
SAE	Society of Automotive Engineers
IMU	Inertial Measurement Unit
INDOPACOM	Indo-Pacific Command
JLTV	Joint Light Tactical Vehicle
JPO	Joint Program Office
lb	pound
LTV	Light Tactical Vehicle
mph	miles per hour
MR	Motion Resistance
M+S	Mud and Snow
MSS	Mud Sand and Snow
NATO	North Atlantic Treaty Organization

NORTHCOM	Northern Command
NSN	National Stock Number
PD-LTV	Product Director – Light Tactical Vehicle
PEO	Program Executive Office
PM	Program Manager
PS	Prepositioned Stock
psi	pounds per square inch
R&D	Research and Development
RDTE	Research Development Testing and Evaluation
S&T	Science and Technology
US	United States
USARAK	US Army Alaska
3PMSF	Three Peak Mountain SnowFlake