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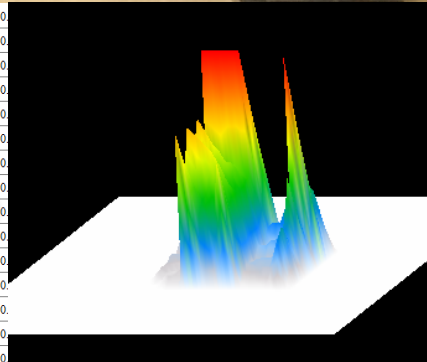
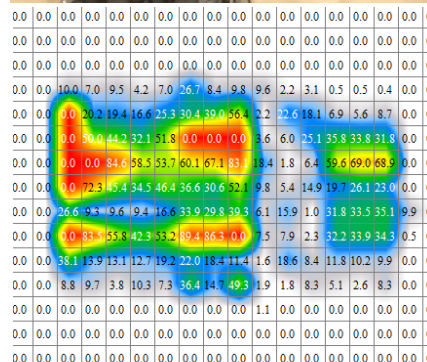


Engineering for Polar Operations, Logistics, and Research (EPOLAR)

Snow-Road Light-Truck Tire Testing

Terry D. Melendy Jr., Amelia Menke, Daphnie C. Friedman,
and Reed R. Winter

February 2020



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Snow-Road Light-Truck Tire Testing

Terry D. Melendy Jr., Amelia Menke, Daphnie C. Friedman, and Reed R. Winter

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Final Report

Approved for public release; distribution is unlimited.

Prepared for National Science Foundation, Office of Polar Programs
Antarctic Infrastructure and Logistics
2415 Eisenhower Avenue
Alexandria, VA 22314

Under Engineering for Polar Operations, Logistics, and Research (EPOLAR)
EP-ANT16-22, "Light Truck Fleet Tire Testing"

Abstract

The United States Antarctic Program (USAP) anticipates replacing the light-truck fleet in the next 2–5 years and requested a detailed look at the potential tires to be used for ice-shelf work. The USAP fleet management team has worked to reduce the curb weight of potential truck options in an effort to minimize the impact on the snow roads. With current Ford F-350 pickups weighing in at 7840 lb empty and a ground pressure of approximately 17 psi, selecting a lighter truck frame would present major advantages. Similarly, operating the current Mattracks (track system in lieu of tires) installed on some of the light-truck fleet has run between \$35 and \$50 an hour over the past 6 years, costing the USAP program as much as \$40,000 per season per vehicle. A light truck on tires, for comparison, operated at \$6 per hour at McMurdo Station over the same time span.

Following testing of nine different types of tires, this report concludes that a suitable tire replacement for the light-truck fleet is commercially available. The BFGoodrich K2, particularly in the Light Truck 32.8 in. (nominally 33 in.) diameter size (BFG LT33), shows significant advantages at all sizes in this tread pattern.

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Preface

This study was conducted for the National Science Foundation (NSF), Office of Polar Programs (OPP), Antarctic Infrastructure and Logistics (AIL), under Engineering for Polar Operations, Logistics, and Research (EPO-LAR) EP-ANT16-22, “Light Truck Fleet Tire Testing.” The technical monitor was Ms. Margaret Knuth, Operations Manager, NSF-OPP-AIL, U.S. Antarctic Program.

The work was performed by the Force Projection and Sustainment Branch (CEERD-RRH) of the Research and Engineering Division (CEERD-RR), U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL). At the time of publication, Mr. Justin Putnam was Acting Chief, CEERD-RRH; and Mr. J. D. Horne was Chief, CEERD-RR. The Deputy Director of ERDC-CRREL was Mr. David B. Ringelberg, and the Director was Dr. Joseph L. Corriveau.

COL Teresa A. Schlosser was Commander of ERDC, and Dr. David W. Pittman was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
inches	0.0254	meters
miles (U.S. statute)	1,609.347	meters
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
square inches	6.4516 E-04	square meters

1 Introduction

1.1 Background

The United States Antarctic Program (USAP) currently operates Ford F-350 pickups as a primary mode of transportation (Figure 1). These vehicles are vital for logistics and maintenance personnel and travel primarily on compacted snow roads. Travel on the snow roads can be difficult, especially during the warmer summer months. Vehicles designed for low ground pressure (i.e., tracked vehicles) are well suited to the terrain while wheeled vehicles often get stuck or create deep ruts in the snow roads.

Figure 1. Ford F-350 pickup on 35 in. diameter Mickey Thompson tires.



An F-350 truck as configured for Antarctica typically weighs 7840 lb, producing an average weight of 1930 lb per tire without cargo. The trucks have lifted suspensions and are outfitted with 35 to 39 in. Mickey Thompson tires, which were selected based on a previous study. The tires are inflated to 18 psi during the summer months, with the tire pressure increased to 30 psi in the winter months (Shoop et al. 2010). The McMurdo Fleet has 48 of these model year 2002 F-350 trucks. The cost to operate and maintain the fleet is approximately \$315,000 per year (Melendy 2014).

1.2 Objectives

The manufacturer has discontinued the currently used and preferred Mickey Thompson tires; and with replacement tires becoming scarce, a suitable alternative is vital. Therefore, the purpose of this project was to identify a suitable replacement tire for the fleet. In conducting the necessary testing, we were also able to identify performance metrics to guide future tire selection. This project allowed us to determine the impact of tire size and vehicle total load on the performance of the tires and transportation system as a whole. We tested 10 different tire types or sizes at six different tire loads and four different tire pressures. As a result, we were able to successfully identify a replacement for the current tire and ideal maximum tire loads to increase the light-truck performance while limiting the impacts of snow-road traffic

For light trucks, a popular alternative to operating on pneumatic tires is Mattracks (<http://www.mattracks.co/>). USAP has outfitted six of the same Ford F-350 vehicles with this adaptation (Figure 2). By implementing a track system on these vehicles, snow surface performance greatly improves. However, the overall operating cost also increases by a factor of ten due to the purchase and installation cost of the equipment, plus increased maintenance costs. A motivating goal of this research was to find a tire that could bridge the gap in performance between Mattracks and the pneumatic tires used in the past.

Figure 2. Ford F-350 Pickup truck on Mattracks.



1.3 Approach

This project tested various options for pneumatic tires that fit the criteria of being between 32 and 40 in. in diameter. The reason for this criteria is that a commercially available full-size truck can easily be modified to fit tires in this range. Part of the decision process in the tire selection was based on bulk availability as the Antarctic program requires many duplicate tires and future tire purchases of the same model would be desirable.

We tested the selected tires on CRREL's specially designed terrain interaction research equipment at various loading rates and tire pressures. Performance of each tire was based on the measured ground force exhibited by each tire at each loading level and at each internal tire pressure. We selected the external ground force as the driving component of performance due to the limited strength of the snow roads present in Antarctica. The ability to preserve these pieces of infrastructure would increase the mobility of equipment and production of logistics transfer.

2 Procedure

The T.I.R.E (terrain interaction research equipment) apparatus (Figure 3) allows researchers to apply a specific load to a single tire. In conjunction with the T.I.R.E., we used a Tactilus mat system (<http://tactilus.net/>) from Sensor Products Inc. to record the ground pressure of each tire. The Tactilus system records pressures within the range of 0 to 100 psi. Sensors are distributed within a 30 × 30 in. mat in a 1 × 1 in. matrix.

Figure 3. T.I.R.E. testing apparatus with a Tactilus mat.

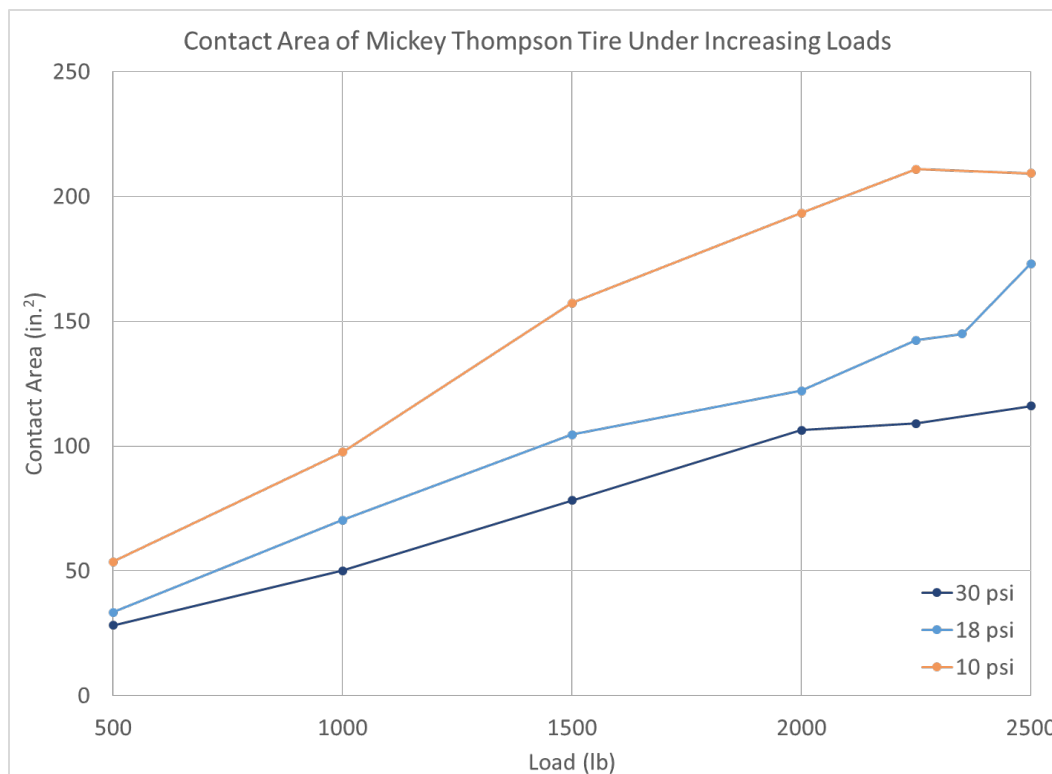


A series of straightforward tests using the Mickey Thompson tire, our baseline, allowed us to establish test procedures and to ensure suitability of the apparatus for proposed testing. This initial testing allowed comparison of the results to expected outcomes according to principles of tire behavior. By its nature, a tire (flexible annulus) transfers a normal load applied at its center and parallel to its radii to a hard surface tangent to its circumference via the captured air pressure in the annulus and, to a smaller degree, the tire's sidewall strength. Thus, for a given normal load and tire, a decrease in the tire's air pressure should result in an increase in the area of contact with the hard surface. Similarly, for a fixed tire pressure, a given tire should show increasing contact area when the normal load is increased.

The Tactilus mat can accurately measure contact area since its individual cells will register a load where the tire exerts any force on the mat and no

load where the tire is not in contact with the mat. Figure 4 illustrates the results of baseline tests conducted on the Mickey Thompson tire. This test series showed a direct linear relationship between normal load and contact area and an inverse relationship between contact area and inflation pressure.

Figure 4. Area of contact between the Mickey Thompson tire and the hard surface measured by the Tactilus mat at selected tire pressures and normal loads.

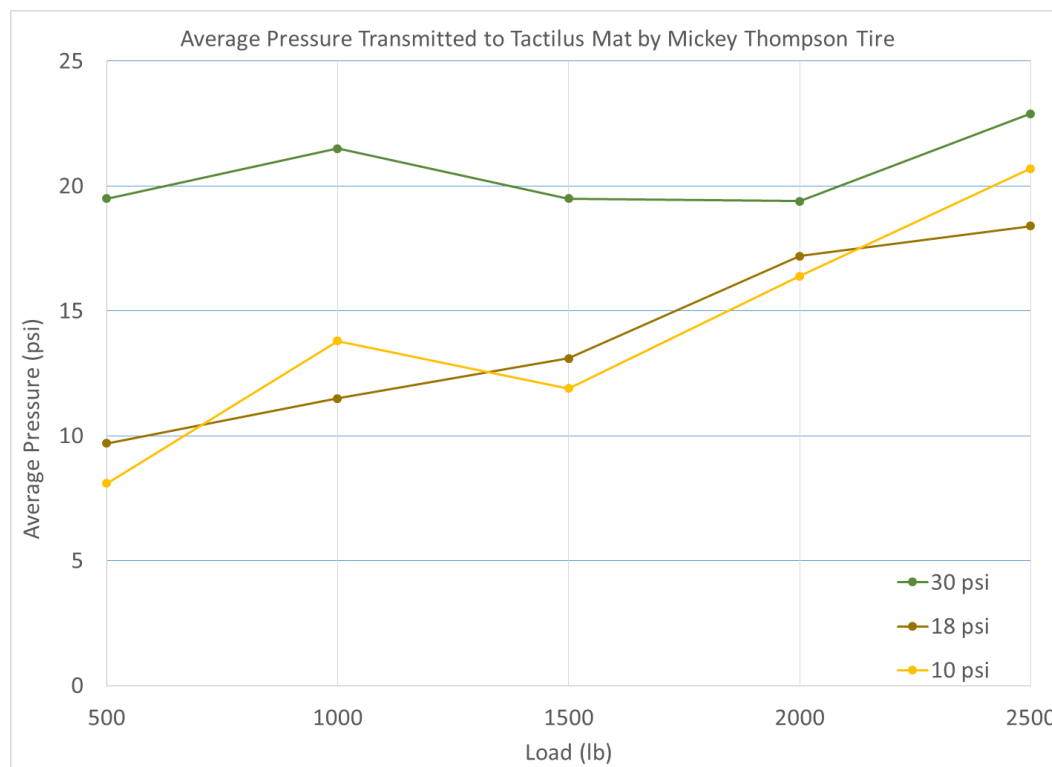


The Tactilus mat allowed us to record average contact pressure as well as point contact pressures in a two-dimensional grid. The inflation pressure within a tire does not translate directly into contact pressure on the ground. A typical method of calculating contact pressure is to divide normal load on the tire by the measured contact area, which is difficult to determine accurately. This method produces an average contact pressure but does not give a complete understanding of the tire's interaction with the roadway. A tire's sidewall, tread, and belt design can have a profound influence on localized contact pressures.

In addition to the contact area, our baseline testing of the Mickey Thompson tire provided pressure data. From this series of tests, we found the average measured pressure within the contact area and plotted it in relation

to the normal load on an individual tire (Figure 5). This revealed a trend of increasing average contact pressure with increasing normal load on a tire.

Figure 5. Average contact pressure calculated from Tactilus mat cell readings as a function of normal load for the Mickey Thompson tire at selected tire pressures.



The results of initial testing with the Mickey Thompson tire provided confidence in the test procedure and equipment. These tests exhibited the expected behavior of a pneumatic tire. Additionally, they confirmed that the Tactilus mat was robust enough for the scale of loads involved and suitable for the nature of the dynamic contact between a flexible tire and hard surface.

Following the established testing procedure, we tested nine additional tires for comparison to the currently used Mickey Thompson tire. Using one tire type at a time, we measured contact pressures and areas at selected tire pressures (7, 10, 18, and 30 psi) across a range of normal loads from 500 to 2500 lb.

3 Tires Tested

We selected 10 tires representing a range of sizes, tread patterns, and manufacturers (Table 1, info in part provided by BFGoodrich [2019]). As previously discussed, the manufacturer discontinued the Mickey Thompson tires that USAP currently uses. A set of these Mickey Thompson tires were included in the testing but were in a worn condition and were tested as a control. The proposed replacement tires, with the exception of the Arctic Truck tire, are commercially available off the shelf in the United States. The Arctic Truck tire is available for purchase through the Arctic Truck Group, located in Iceland.

The selected tires range in cost from about \$200 to \$1500. The most expensive tire tested was the Arctic Truck tire, which is marketed specifically for snow applications. The tires tested range from 31 to 38 in. in diameter. Additionally, the tread patterns on the tires tested ranged from very aggressive to much less so (Figure 6).

Table 1. Tires tested

Tire	Tire Size	Maximum Load (lb)	Maximum Tire Pressure (psi)	Overall Diameter (in.)	Tread Depth (in.)	Cost
Mickey Thompson	36x14.50-16	3045	30	N/A	N/A	\$300
Arctic Truck	38x15.50-16	3010	30	38.25	25/32	\$1500
Super Swamper 38 (ICT-SSR-65-R)	38x15.50-15	3000	65	38.2	21/32	\$550
Super Swamper 35 (ICT-SSR-28R)	35x14.00-15	2680	35	35.2	21/32	\$475
Super Swamper 33 (ICT-SAM-50)	33x15.5-15	2415	30	33.1	23/32	\$336
Mud Grappler (NIT-200580)	35x14.00-15	2755	35	34.8	21/32	\$340
BFG 35 (BFG-66539)	35x12.50-17	3195	65	34.5	15/32	\$310
BFG 33 (BFG-37881)	33x12.50-15	2205	35	32.5	15/32	\$208
BFG LT33 (BFG-99728)	285/70-17	3195	80	32.8	15/32	\$242

N/A = not available

Note: BFG tires were all BFGoodrich K2 tread patterns.

Figure 6. Tire treads of tires tested: (a) Mickey Thompson (light wear), (b) Mickey Thompson (heavy wear), (c) Arctic Truck, (d) Super Swamper 38, (e) Super Swamper 35, (f) Mud Grappler, (g) BFG 35, (h) BFG 35 (modified), (i) BFG 33, (j) BFG LT33.



We also performed a tread modification on several of the tires to examine the effect of wear on tire performance. The tires had the exterior walls of the tread ground down to simulate wear. This created rounded edges on the tire as shown in Figure 7. Additionally, simulating wear on the tire was performed to calculate the possible life span of tires as they are used at McMurdo Station. A goal of this work was to determine if performance of the tires decreased with tread reduction.

Figure 7. BFG 35 tire with simulated wear (*right side, shown with arrow*).



4 Results

Testing for each tire resulted in a substantial amount of data to be processed as multiple variables are present for each test, including load, internal tire pressure, and tire type. Tire type encompasses differences in tread pattern and in diameter and width. To analyze the effect of each variable, we tested each tire at a series of set internal tire pressures and loads. Because of the sheer number of tests conducted, we analyzed only the overall best-performing tires on each variable.

4.1 Ground contact pressure

The primary consideration for determining performance is ground pressure. Low overall ground pressure is essential to preserve the integrity of the McMurdo area snow roads, particularly during warm weather. Improved performance of tires at McMurdo would directly reduce maintenance time and cost associated with maintaining the 11 miles of snow roads (Melendy and Shoop 2017). The snow roads are a vital life line to the runways at McMurdo and to Antarctica overall.

To rank tire performance in this metric, we considered both average pressure measured by the Tactilus mat and the number of cells reaching maximum capacity. The number of maxed cells, those reading 100 psi or greater, is an indication of high point loads. High average ground pressure and high point loads are likely indicators of poor performance. The pressure maps produced by the Tactilus mat also illustrate the pressure distribution patterns of the individual tires. Appendix A includes these pressure maps for all tires, and Figure 8 shows selected images.

Figures 9 and 10 show the average ground pressure of the top six performing tires under 1000, 1500, and 2000 lb individual tire loads at 18 psi and 30 psi. As Figure 11 illustrates, the same tires performed well in regard to point loading with relatively few cells detecting pressures greater than 100 psi. The BFG LT33 performed the best in each of the load interval tests (each loading level), even in comparison to the existing control tire (Mickey Thompson). The BFG 33 was a close second in performance. Figures 9–11 also illustrate that, as tire loads increase, average ground contact pressure increases.

Figure 8. Tactilus pressure maps of the best- (*left*) and worst- (*right*) performing tires at 18 psi with a 1500 lb load.

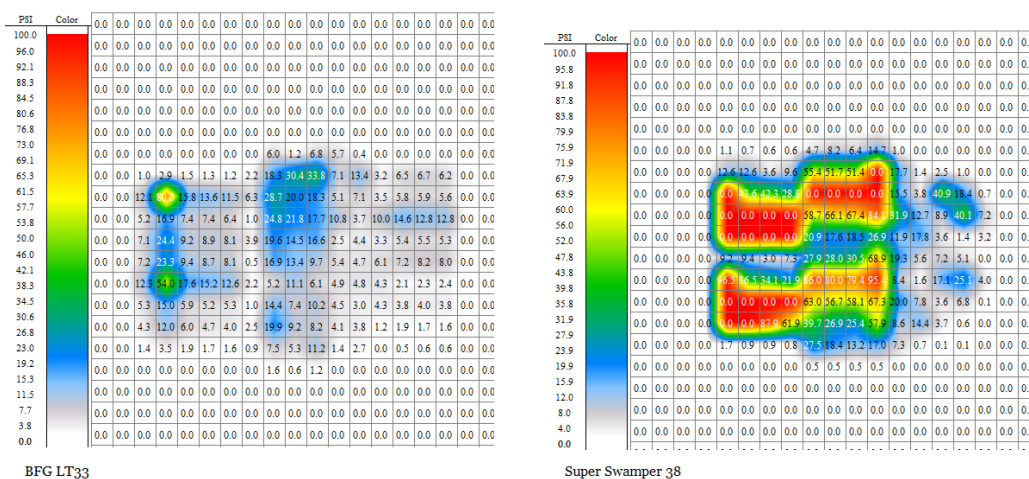


Figure 9. Average contact pressures at 18 psi.

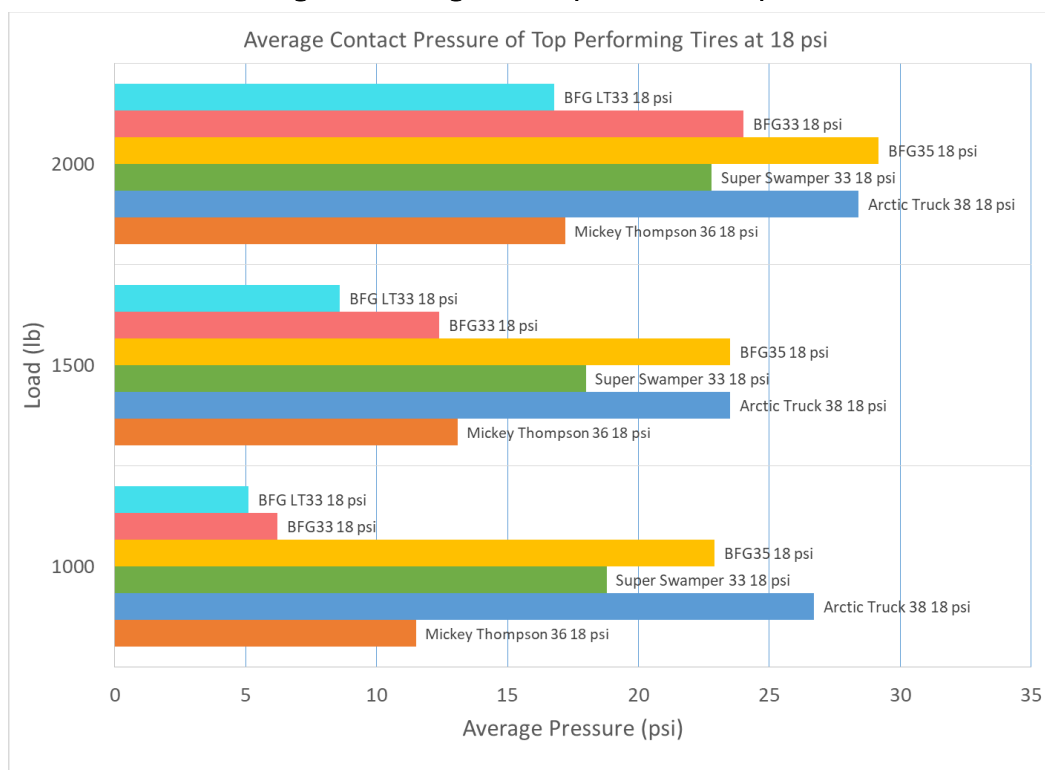


Figure 10. Average contact pressures at 30 psi.

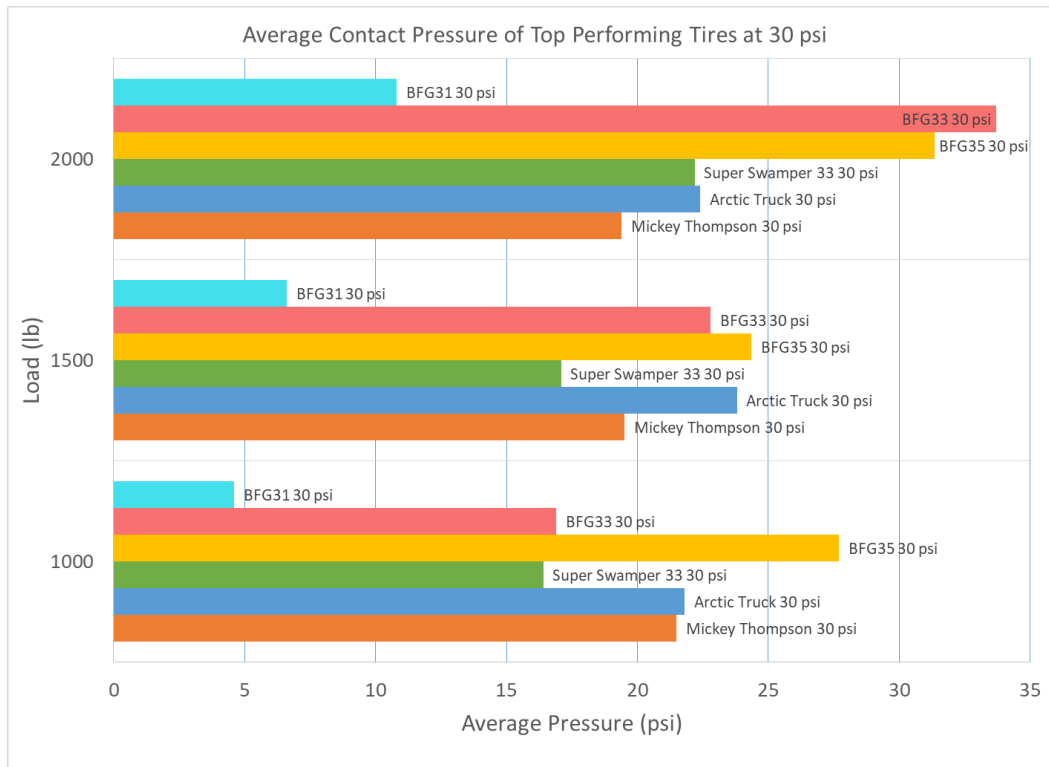
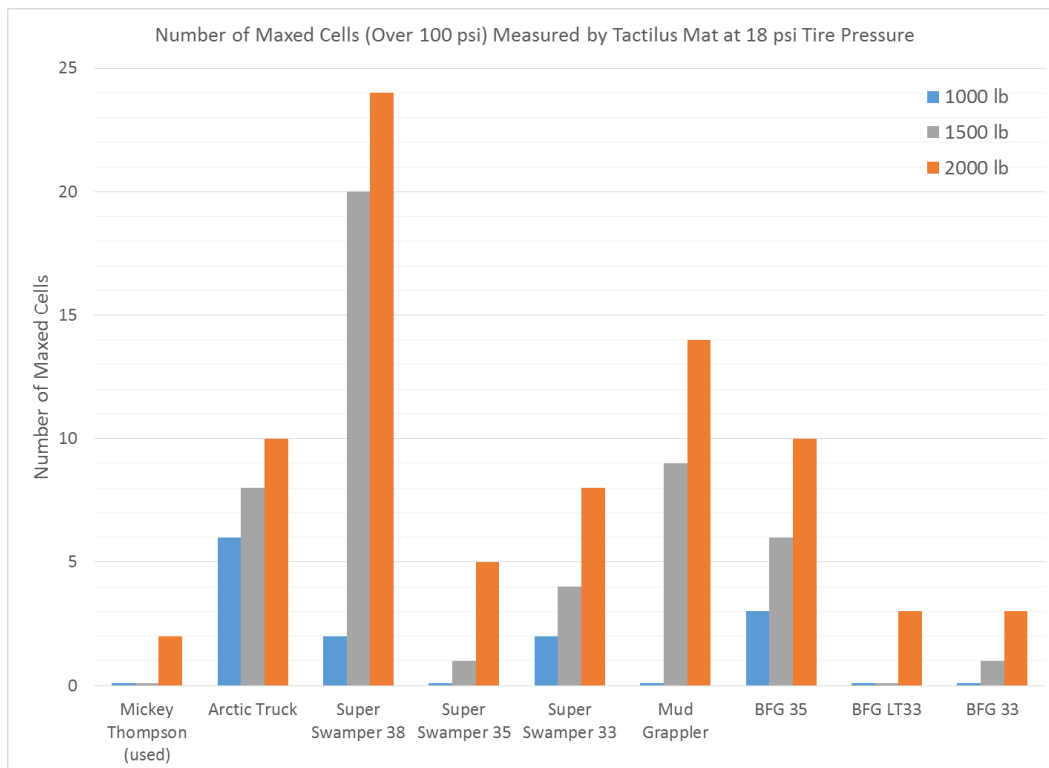


Figure 11. Number of cells detecting over 100 psi contact pressure by tires at 18 psi under 1000, 1500, and 2000 lb loads.



4.2 Tire load

We tested each tire at loads ranging from 500 to 2500 lb. Performance in the 1500 to 2000 lb range is of particular interest because this range encompasses the per-tire load of a 6000 to 8000 lb truck. Trucks in the current fleet are within this range at the upper end. These tests revealed that the most significant and consistent determinant of performance is tire load. Greater tire loads resulted in increased average contact pressure as well as more frequent high point loads (section 4.1). Figures 12–14 illustrate this relationship at tire pressures of 10 psi, 18 psi, and 30 psi.

Tire load is a variable independent of tire type and model selection. While the purpose of this study was to identify tires suitable for use in Antarctica, gross vehicle weight is an important additional consideration. Section 5 discusses further implications.

Figure 12. Average contact pressure of all tires at 10 psi under increasing loads.

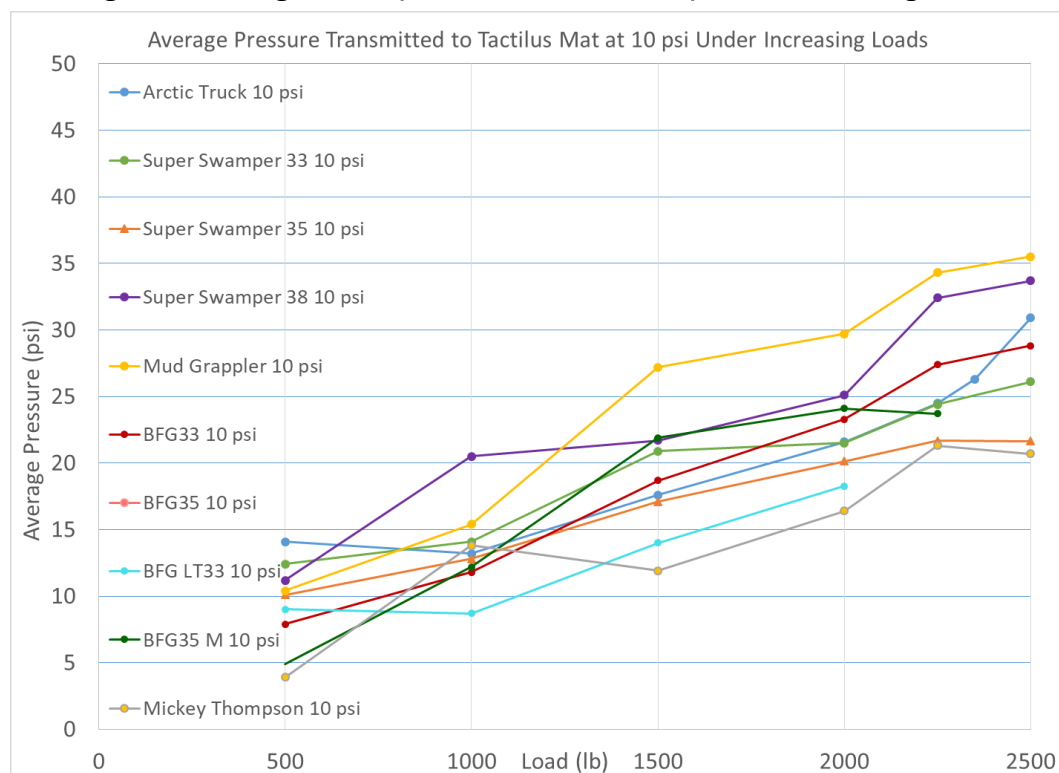
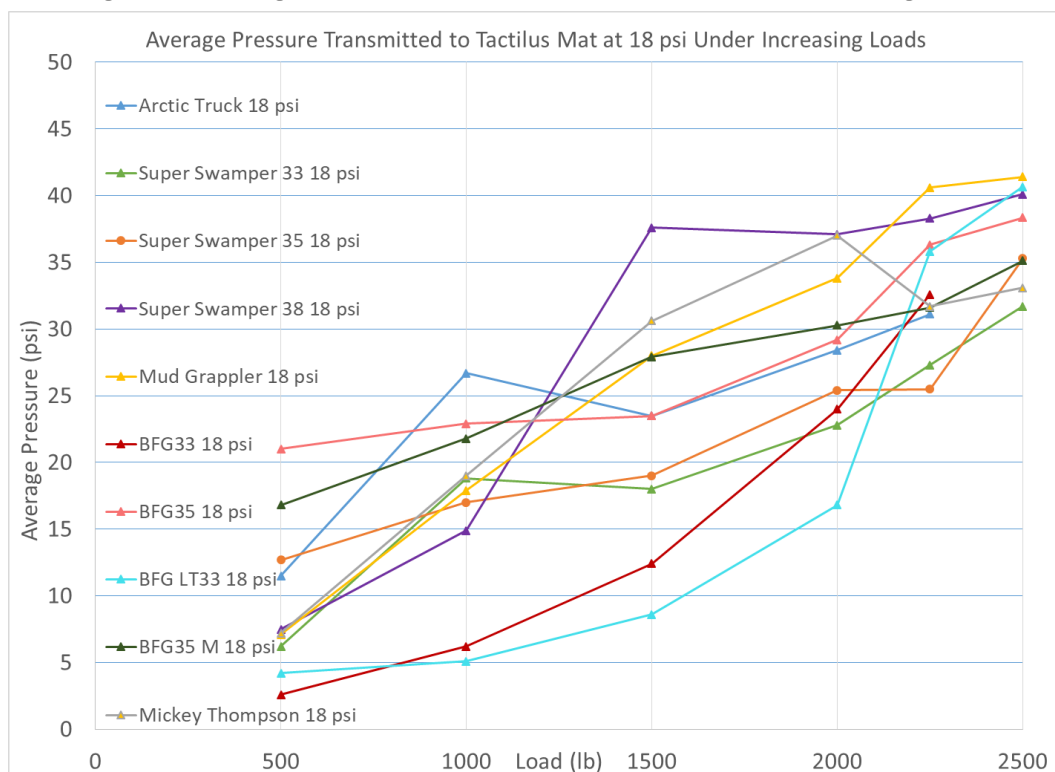
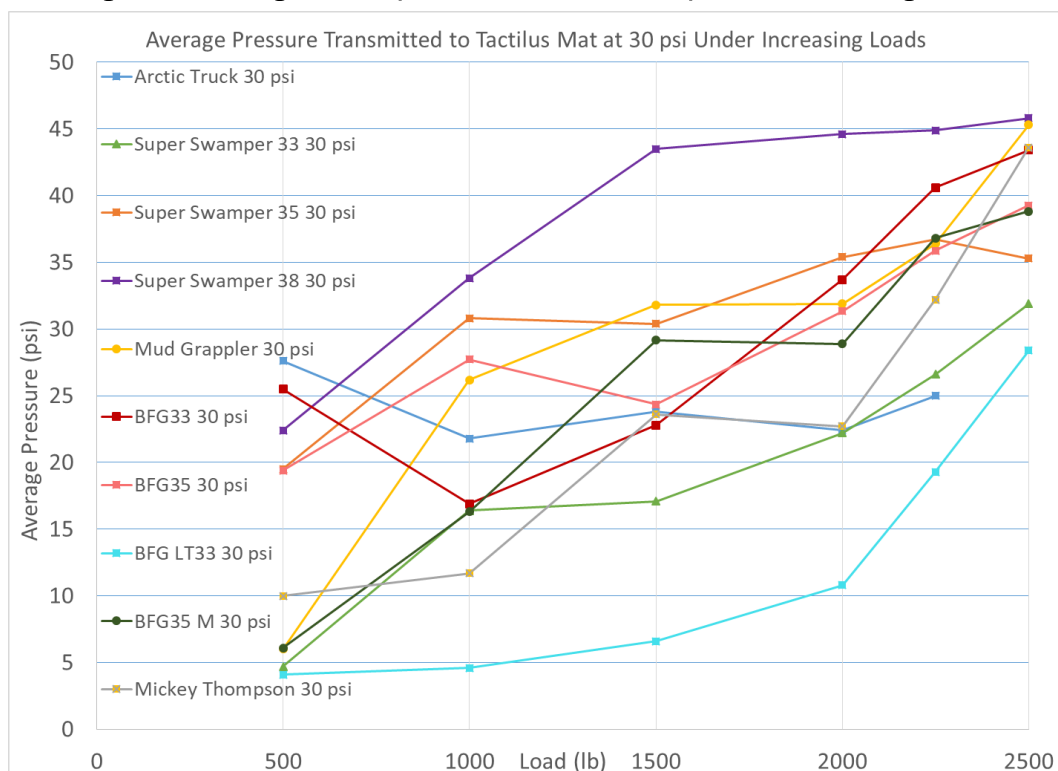


Figure 13. Average contact pressure of all tires at 18 psi under increasing loads.**Figure 14. Average contact pressure of all tires at 30 psi under increasing loads.**

4.3 Contact area

The Tactilus mat measured the total contact area of the tire for each test. USAP initially considered greater contact area desirable because the vehicle's weight would be distributed over a larger area, which could result in lower contact pressures. In the past, larger tires have been favored because of an assumed benefit following this logic. However, results indicate that contact area does not consistently correlate to low average contact pressure (Figure 15). Based on our testing, performance actually decreased with an increase in tire diameter in spite of the increase in contact area. A couple of reasons account for this, such as the increased weight of larger tires and the rubber compounds used on larger tires being stiffer and less flexible. Also, larger tires typically have larger, more aggressive tread patterns with sharp edges that correlate to increases in contact pressures at the tread edges.

Low internal tire pressure is strongly correlated to increased contact area for all tires tested, as shown in Figure 16. Higher loads (Figure 17) also strongly correlate to increased contact area. In addition, the tire size, tread pattern, and sidewall stiffness influence the total contact area. These factors, which are more difficult to quantify, vary widely between the tire types tested.

Figure 15. Contact area versus average contact pressure for all tires at 1500 and 2000 lb loads. Note the lack of positive or negative correlation.

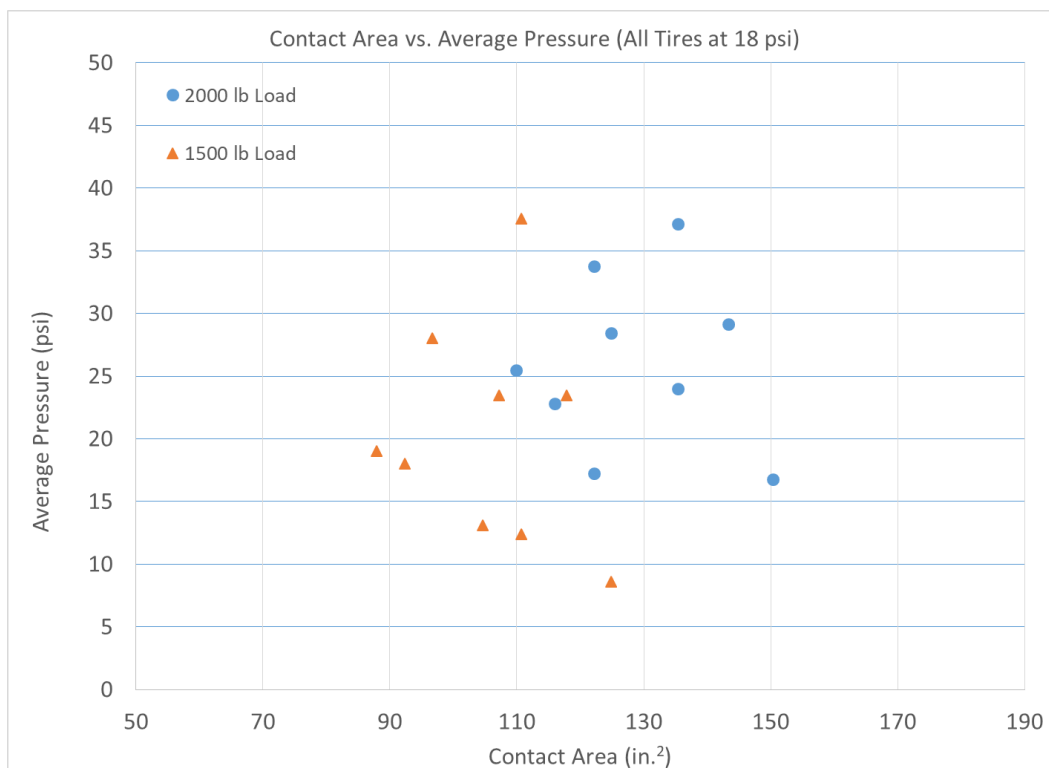


Figure 16. Total contact area of selected tires under a 1500 lb load across a range of internal tire pressures.

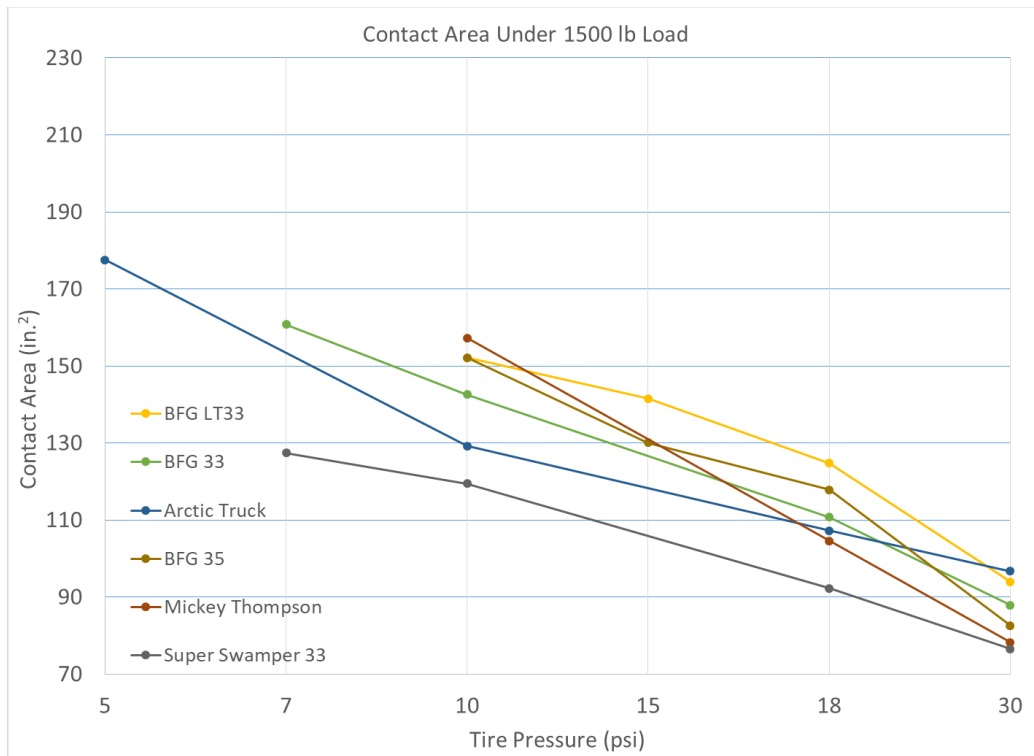
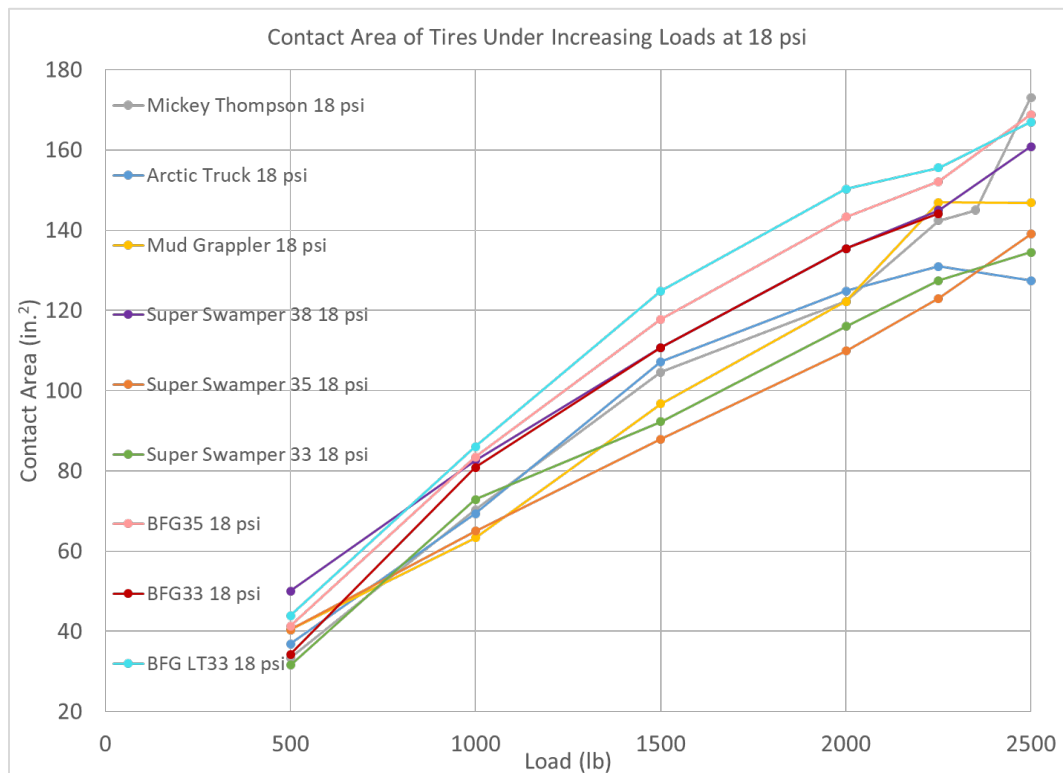


Figure 17. Total contact area of selected tires at 18 psi internal tire pressure across a range of loads.



To control for some of the factors associated with tire type, we examined three tires that are identical except for size. The Super Swamper tire was tested in 33, 35, and 38 in. diameter models. Figures 18 and 19 show the results of this comparison. While the largest tire, the Super Swamper 38, consistently had the greatest contact area, it also performed the worst. Though it performed slightly better in the light load range, average contact pressure of the 38 in. tire was much greater than that of the smaller versions within our target load range of 1500 to 2000 lb.

Contact area and tire size alone are not good predictors of performance. However, a comparison of all tires tested at the same internal tire pressure and load (18 psi and 2000 lb) reveals a trend towards higher average ground pressure with greater tire diameter (Figure 20).

Figure 18. Contact area of three sizes of Super Swamper tires at 18 psi internal tire pressure under a range of loads.

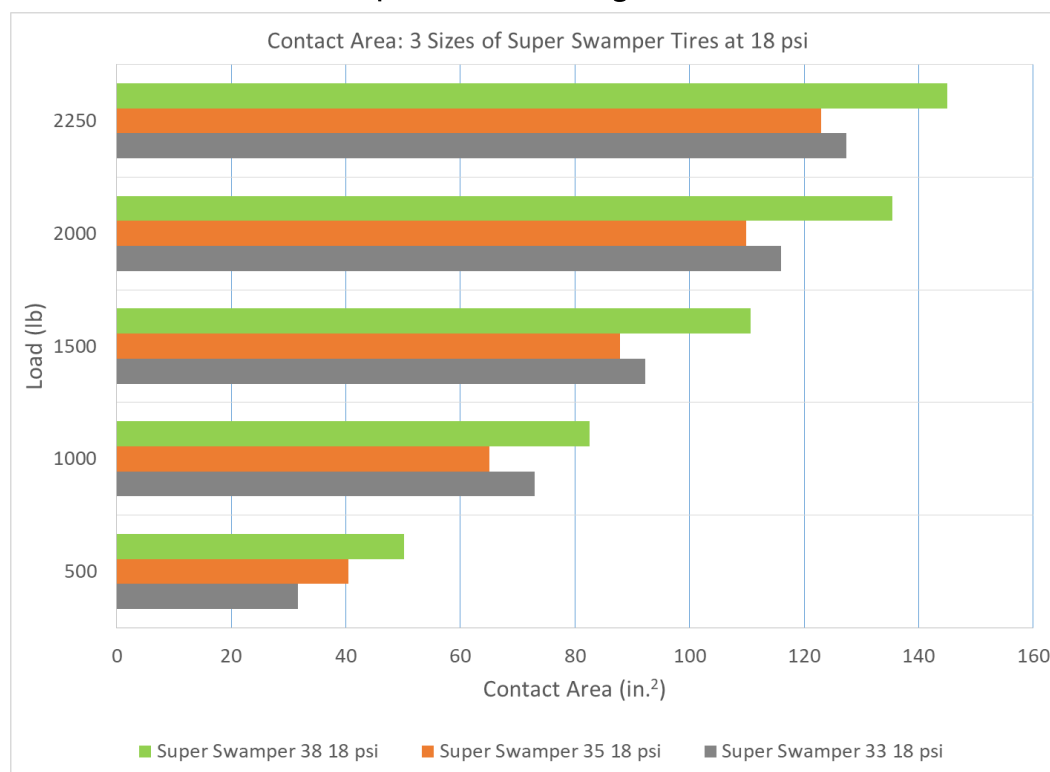


Figure 19. Average contact pressure of three sizes of Super Swamper tires at 18 psi internal tire pressure under a range of loads.

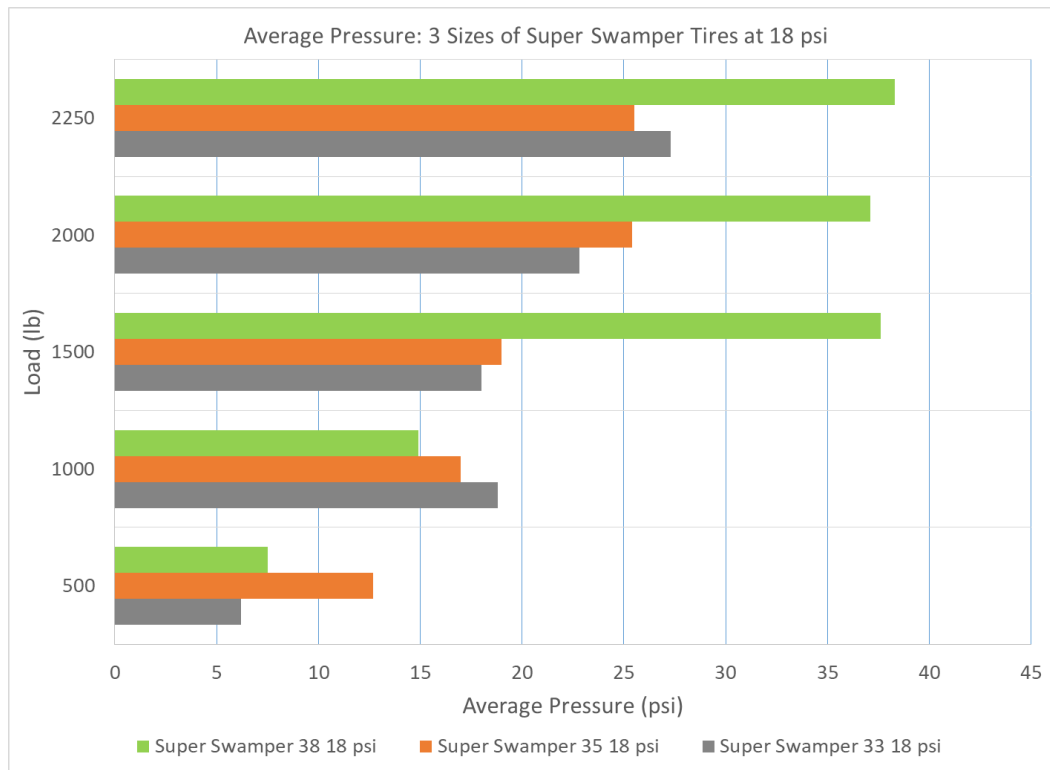
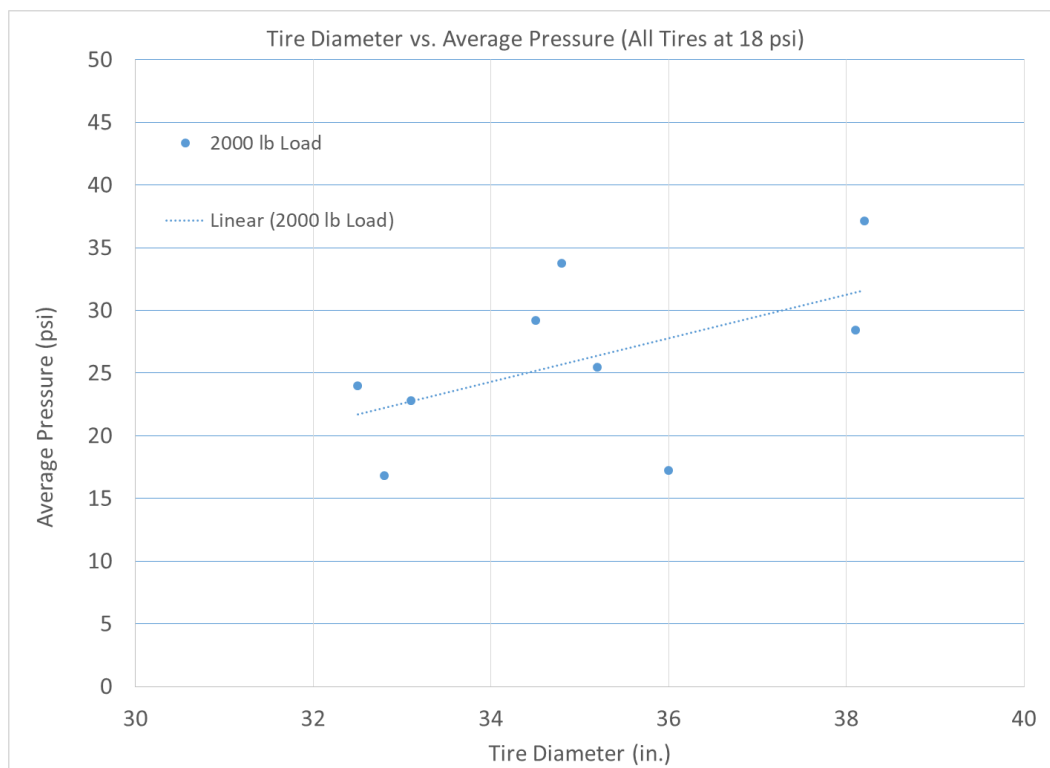


Figure 20. Tire diameter versus average contact pressure of all tires tested at 18 psi internal pressure under a 2000 lb load with linear trend line.



4.4 Internal tire pressure

We tested most of the selected tires at 10, 18, and 30 psi with some additional tests at 5, 7, and 15 psi. The current McMurdo light-truck fleet uses tires inflated to 18–30 psi. Although 10 psi inflation was tested on all of the tire alternatives, it is not realistic for field use. At very low pressures, tires are more likely to roll off of the rim. Off-road vehicles sometimes use underinflated tires, as low as 5 psi; but they also utilize a special bead lock rim, which prevents roll off. USAP's current fleet of light vehicles in Antarctica does not use a bead lock rim system and so are currently not operated at pressures lower than 18 psi to reduce the potential of rim roll. We tested at internal tire pressures below 18 psi with bead lock rims to show what additional performance could be gained, if any, by changing the rim style currently in use.

Tire inflation at McMurdo Station is governed by the operations standard procedure for light vehicles. This standard dictates that internal tire pressure will be reduced to 18 psi during the summer months and increased to 30 psi during winter months. The reasoning for the change in pressures based on season is because past research (Shoop et al. 2016) has determined that lower internal tire pressure results in lower ground contact pressures. The reduced tire pressure during the summer months was selected after testing the effects of low tire pressure on the rims and tire to limit the amount of rim roll off and destruction of tire sidewalls.

Figures 21 and 22 compare tire performance at constant loads of 1500 and 2000 lb across a range of internal tire pressures. Changes in performance are noted in a few tires with an overall trend of a slight increase in average ground pressure with increased tire pressure. However, results are mixed. Based on these tests, internal tire pressure did not have a consistent, significant impact on average ground pressure.

Figure 21. Average contact pressure of selected tires under a 1500 lb load as a function of internal tire pressure.

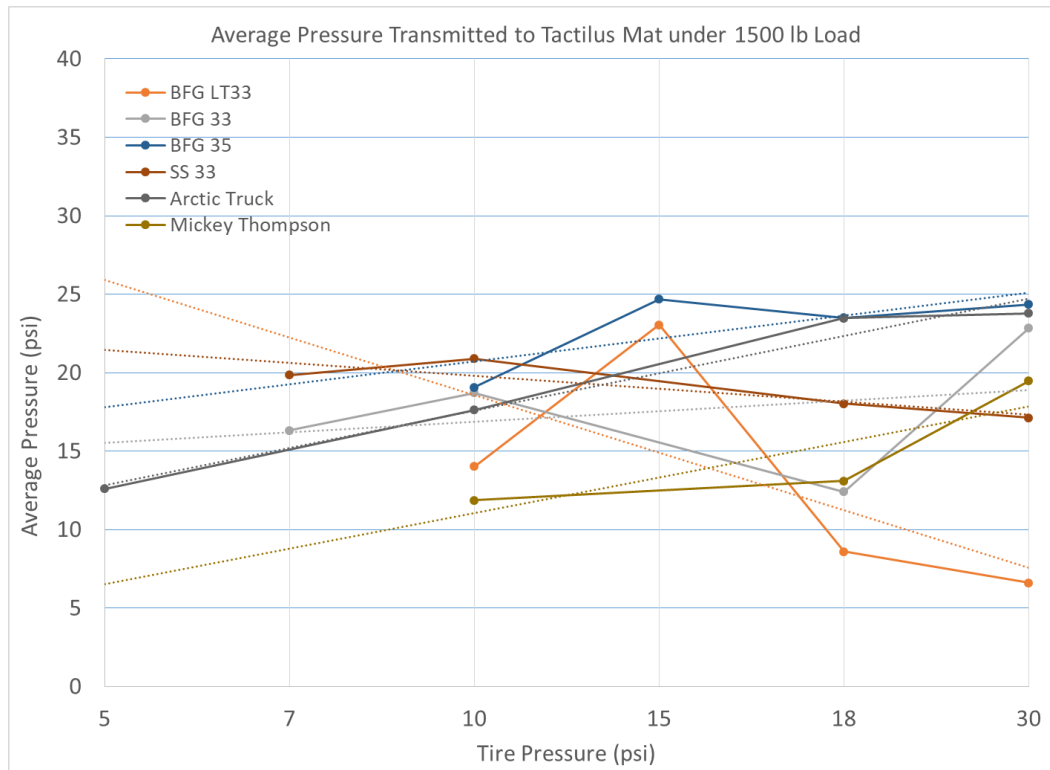
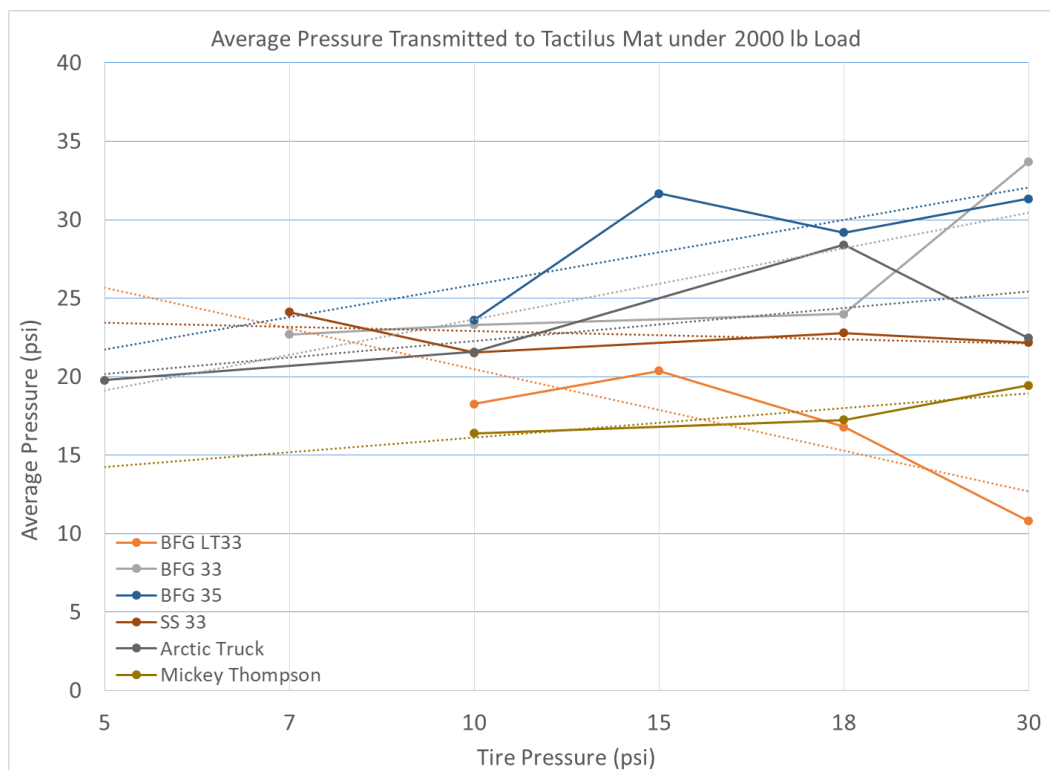


Figure 22. Average contact pressure of selected tires under a 2000 lb load as a function of internal tire pressure.



4.5 Modification

A BFG 35 tire was modified to determine if performance of the tires decreased with tread wear. Corners of the tread were manually filed to simulate the effect of prolonged use. The modified BFG 35 tire was tested with the same procedures as the original version. Results were somewhat mixed. The modified tire typically performed better than or about the same as the factory-condition tire (Figure 23).

Based on these results, overall performance does not appear to degrade with wear and actually improves. This is because wearing of the treads rounds the otherwise sharp edge, reducing the occurrence of high point loads. Over time, tire stiffness will also decrease with field use, which may contribute to reduced contact pressure. This effect was visible in pressure maps of the Mickey Thompson tire, which was only available for testing in a worn condition. The shape of the pressure distribution is much more circular than those of the other, factory new tires as shown in Figure 24. We were able to conclude this by focusing on the newer Mickey Thompson tire compared to the heavily worn version of the same tire.

Figure 23. Comparison of the BFG 35 tire with (*lighter colors*) and without (*darker colors*) simulated tread wear at a range of tires pressures and tire loads.

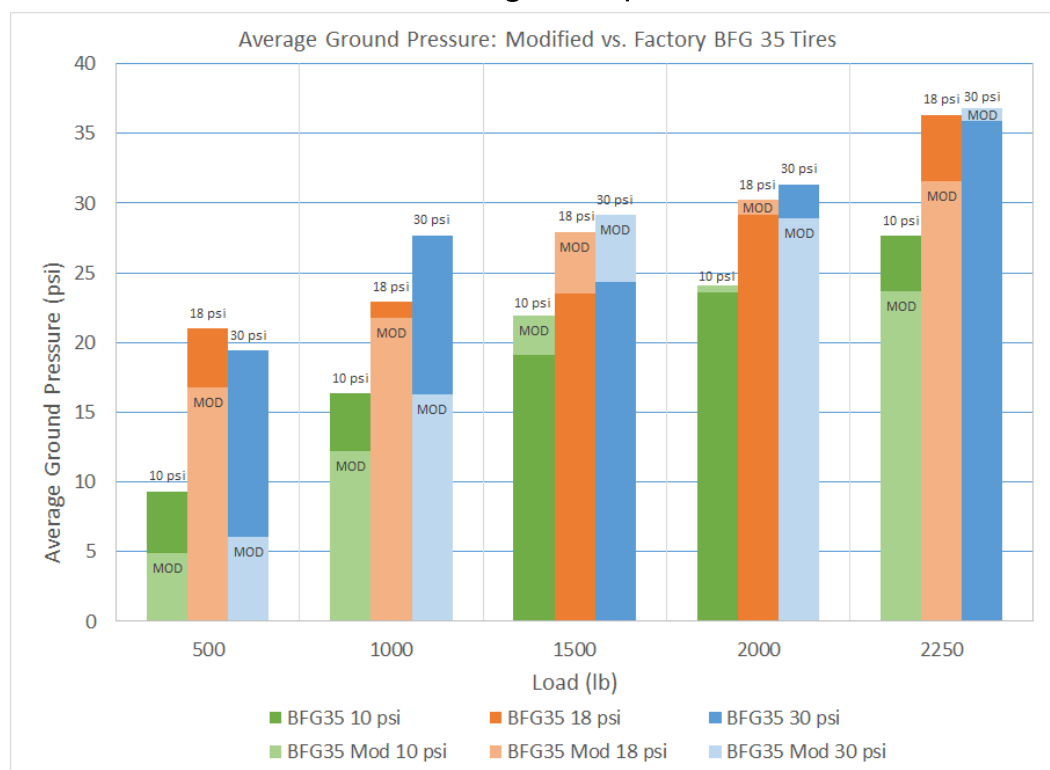
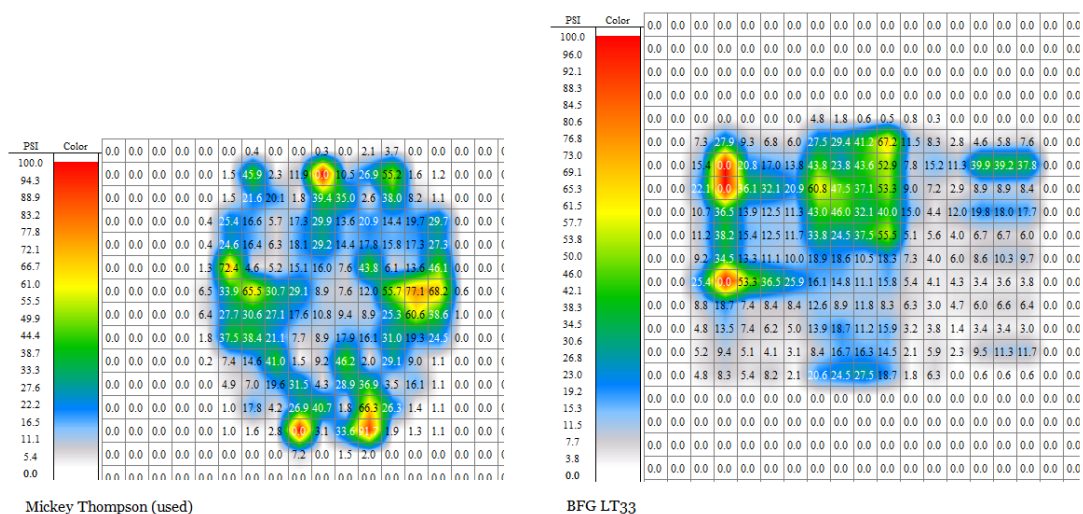


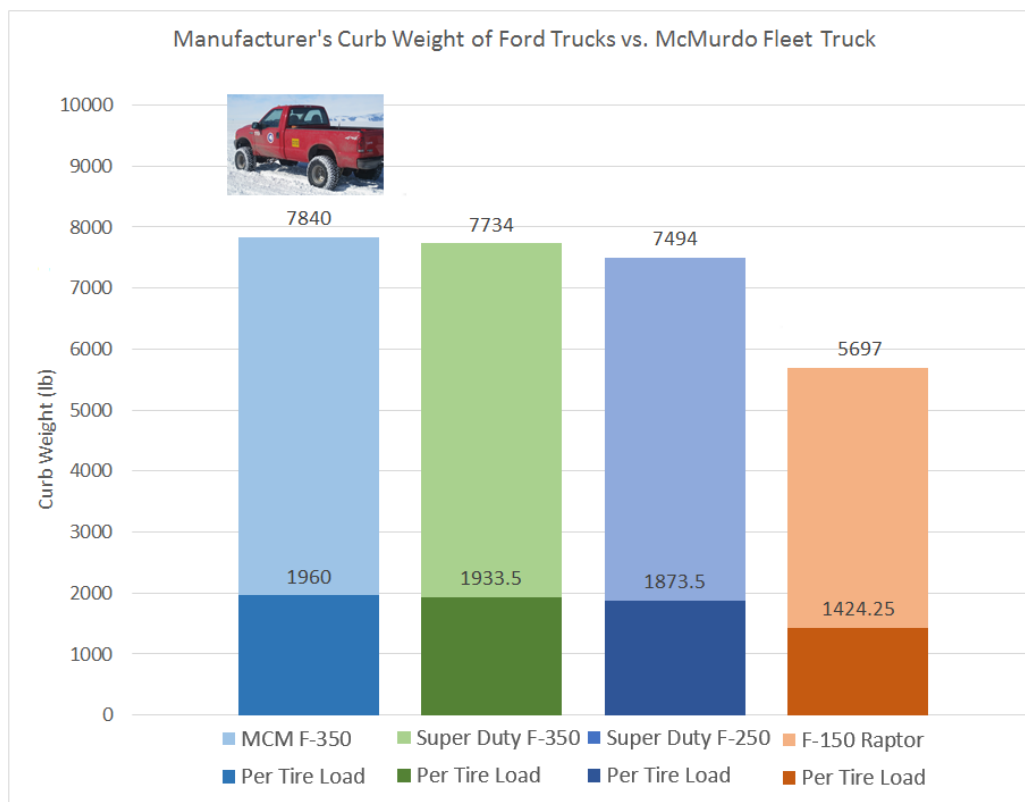
Figure 24. Pressure maps of the BFG LT33 tire (*right*) and the Mickey Thompson tire (*left*) at 18 psi tire pressure under a 2000 lb load.



5 Truck Comparison

In the course of evaluating tires for use by the McMurdo Station light-truck fleet, it is important to consider the truck itself. The current F-350 trucks will eventually be replaced, and compatibility of the tire alternatives studied is an important factor. Additionally, across all tires tested, the strongest correlation is between ground pressure and load. To reduce ground pressure, and thereby reduce impact on the snow roads, reducing overall vehicle weight will have a huge impact. To quantify the effect of reduced vehicle weight, we considered the curb weight of several commercial light trucks compared to those in the current USAP fleet (Figure 25). McMurdo maintenance personnel prefer Fords because of the mechanical repair capabilities located on-site in Antarctica and their current familiarity with this particular brand of light vehicle. Therefore, we evaluated available Ford light-truck models.

Figure 25. Vehicle curb weight comparison.



The Ford Super Duty F-250 and F-350 and the Ford F-150 Raptor are potential replacement vehicles for the light-truck fleet. Estimated curb weight is based on the 2018 specifications from the manufacturer (Ford

Motor Company 2019). Each model weight shown in Figure 25 includes a crew cab configuration with four-wheel drive. The F-150 Raptor is a version of the F-150 that includes an off-road suspension and also accommodates larger tires and a performance package. The Raptor comes standard with LT315/70R17 tires, which are 34.4 in. diameter. The Super Duty trucks can accommodate up to 33 in. diameter tires without modification. All of these options are compatible with the BFG LT33 tire, the best-performing tire identified during our testing.

After-market suspension lifts have been purchased and installed on many of the vehicles used at McMurdo Station. These adaptations are necessary to accommodate large tires, but they are undesirable in several ways. Lifting the vehicle incurs greater expense and adds weight, voids the warranty, and changes the vehicle's center of gravity, which may increase the possibility of rollover. By selecting a vehicle compatible from the factory with the desired tire, these issues listed above can be avoided or reduced. The choice of a model vehicle that is "off the shelf" is also cheaper to operate and maintain due to the availability of factory replacement components and increased component purchasing options.

The Raptor is 28% lighter than the current F-350s at McMurdo, resulting in an expected decrease in contact pressure and increase in performance. Coupled with its compatibility with the best-performing tire tested within this project, a light-truck fleet of Raptors would reduce contact pressure by 43% compared to the current F-350 fleet. Although this project did not focus on the cost savings of off-the-shelf vehicles versus modified, it is widely preferred to choose off-the-shelf vehicles due to the cost of customization, an increase in parts inventory, and aftermarket vendor purchasing of major components, which would further complicate parts ordering in the future. Each of the previously listed negatives for selecting a customized vehicle have resulted in either longer downtime due to waiting for parts, increases in repair costs, or both.

6 Conclusions and Recommendations

To reduce the impact and damage to the snow-road infrastructure, the light wheeled vehicles should exhibit the following characteristics:

1. The curb weight should be as light as possible.
2. The tire size should not be larger than operationally required to traverse the terrain as the snow roads are relatively flat and level and do not require additional ground clearance.
3. The tire tread should not be aggressive, due to the sharp edges associated with aggressive treads; and the tires should not be based off all-terrain road designations as they are not required for the USAP roads.
4. The vehicles selected should be kept as factory stock as possible to reduce initial purchase and operations and maintenance costs.

Based on low contact ground pressure at potential vehicle loads, the BFG LT33 tires performed the best and the BFG 33 tires performed second best. The BFG LT33 (BFGoodrich K2, Light Truck 32.8 in. [nominally 33 in.] diameter size) exhibited characteristics that are ideal for snow-road use by producing the lowest ground contact pressure, by showing minimal high-stress point loading, by being commercially available, and by having higher load capacity than other 33 in. tires. Higher load capacity increases the potential use of the tires so that they can be outfitted on the entire fleet of light vehicles.

The internal tire pressure should be 18 psi as previously stated in Shoop et al. (2010). Figure 23 clearly shows that decreasing the internal tire pressure results in a decrease in contact pressure and improves the tire performance.

Currently bead locks, a type of rim system that allows use of a lower internal tire pressure without rolling the tire off from the rim, are not used on the light-truck fleet but should be considered due to their allowing safe operation at tire pressures lower than 18 psi. While this would improve mobility, it probably would not result in the same performance gains as changing the light-truck vehicle or the tires used.

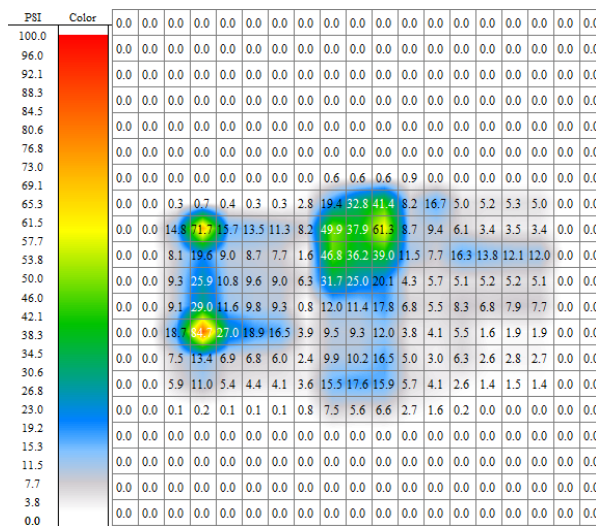
Because wear smooths the sharp edges of the treads, increasing the performance of the tires, we recommend that the tire's life span be dictated by

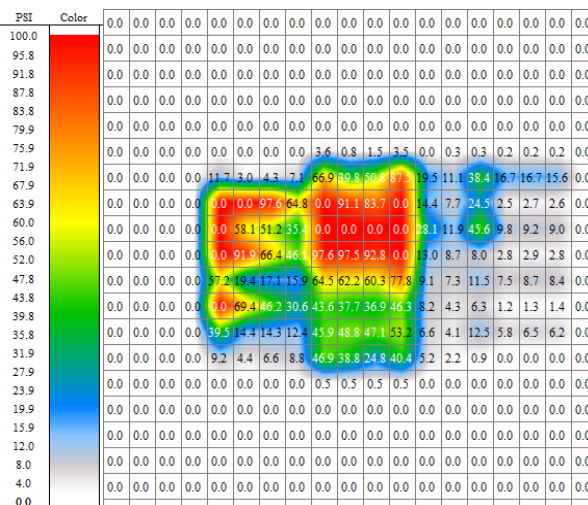
how long the tire can successfully hold air and not show cracks in the sidewalls of the tire. Up to this point, they are still safe to operate for the requirements of McMurdo Station.

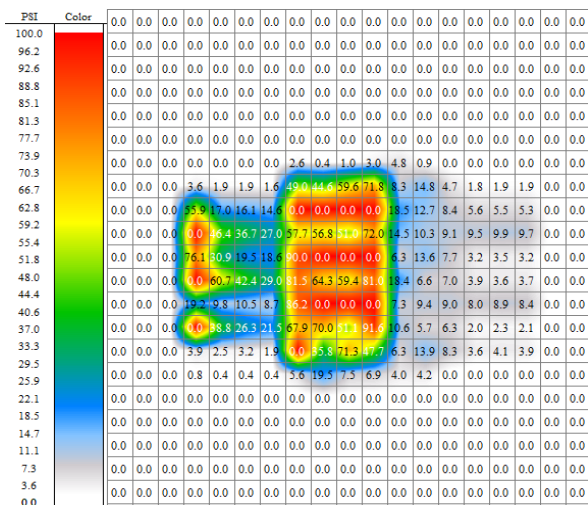
For future selection of tires for the USAP fleet of light vehicles, the contact area of the tire is not a clear indicator of its performance. From this study we have learned that the indicators of high-performance tires for Antarctica depend highly on tire diameter, tread pattern, sidewall stiffness, and internal tire pressure. The lower the contact pressure that the vehicle exhibits, the lower the impact the vehicle will have on the snow roads. Reducing the impact of the vehicles will reduce the snow-road maintenance, transportation times to various locations on the ice shelf, and vehicle and passenger safety concerns, reducing the potential for stranded or immobilized vehicles.

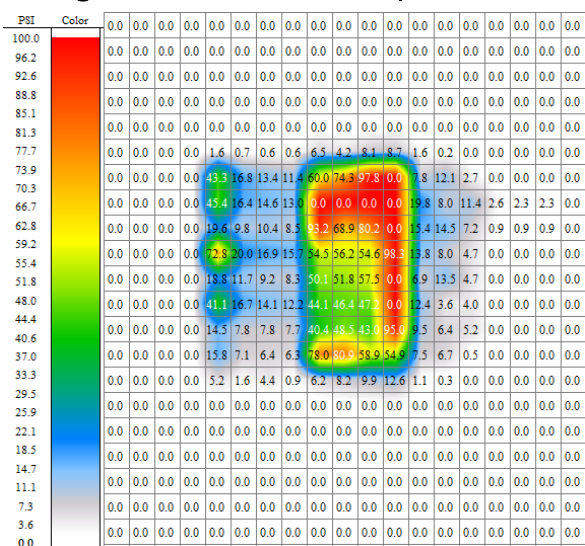
References

- BFGoodrich. 2019. "All-Terrain T/A® KO2." BFGoodrich. <https://www.bfgoodrichtires.com/tire/bf-goodrich/all-terrain-t-a-ko2>.
- Ford Motor Company. 2019. "New Trucks or Pickups." Ford. <https://www.ford.com/new-trucks/>.
- Melendy, T. 2014. *Maintenance Costs of Equipment Owned by the National Science Foundation*. ERDC/CRREL LR-14-6. Hanover, NH: U.S. Army Engineer Research and Development Center.
- Melendy, T. D., and S. Shoop. 2017. *2010/11 McMurdo Station Snow-Road Strength and Maintenance*. ERDC/CRREL TR-17-3. Hanover, NH: U.S. Army Engineer Research and Development Center. <http://hdl.handle.net/11681/21206>.
- Shoop, S. A., G. E. Phetteplace, and W. L. Wieder. 2010. *Snow Roads at McMurdo Station, Antarctica*. ERDC/CRREL TR-10-5. Hanover, NH: U.S. Army Engineer Research and Development Center. <http://hdl.handle.net/11681/5524>.
- Shoop, S. A., J. Uberuaga, W. L. Wieder, and T. D. Melendy. 2016. *Snow-Road Construction and Maintenance*. ERDC/CRREL TR-16-16. Hanover, NH: U.S. Army Engineer Research and Development Center. <http://hdl.handle.net/11681/20651>.









A.5 Arctic Truck Tactilus pressure maps

Figure A-17. Arctic Truck 18 psi 1500 lb.

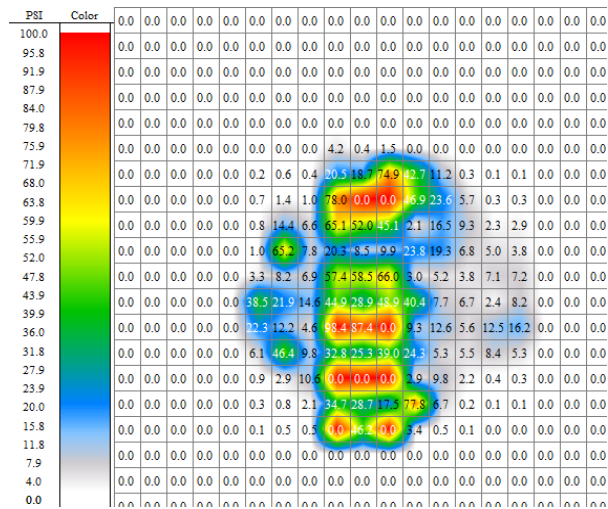


Figure A-18. Arctic Truck 18 psi 2000 lb.

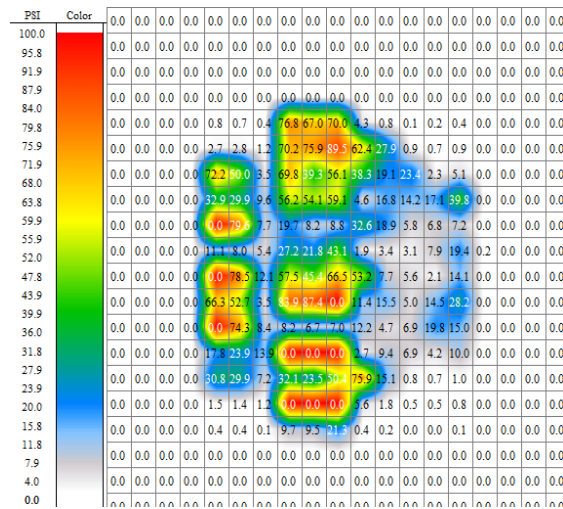


Figure A-19. Arctic Truck 30 psi 1500 lb.

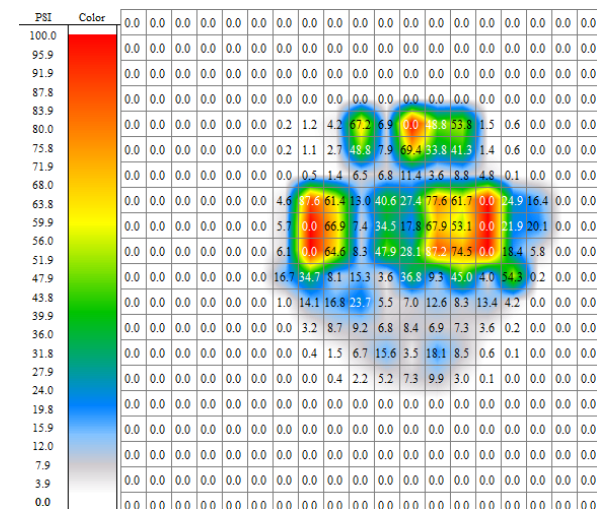
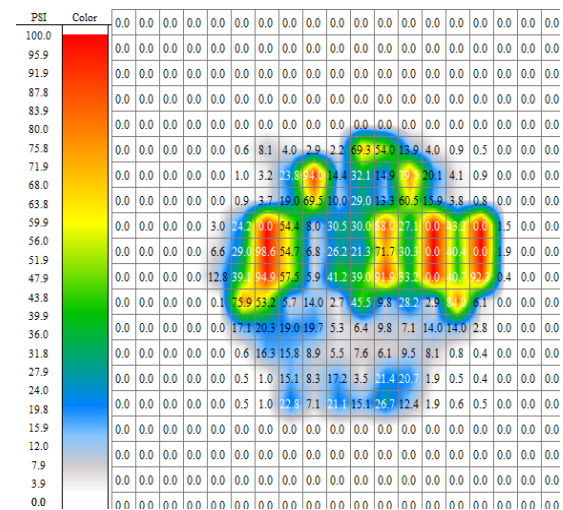
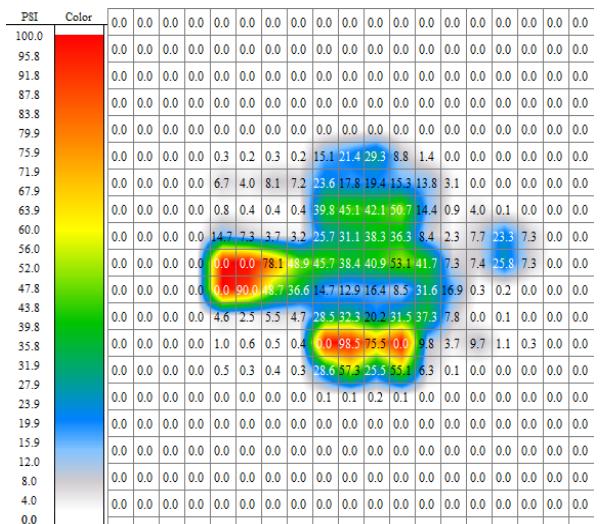
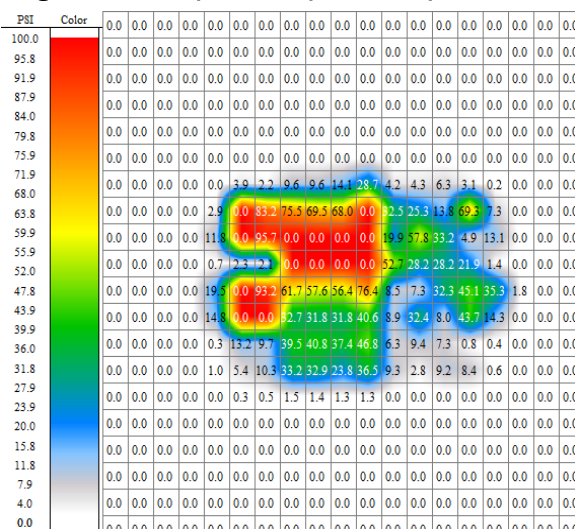


Figure A-20. Arctic Truck 30 psi 2000 lb.







A.8 Super Swamper 38 Tactilus pressure maps

Figure A-29. Super Swamper 38 18 psi 1500 lb.

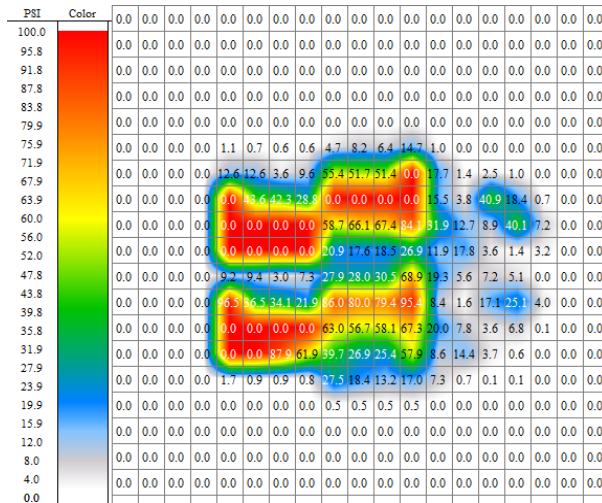


Figure A-30. Super Swamper 38 18 psi 2000 lb.

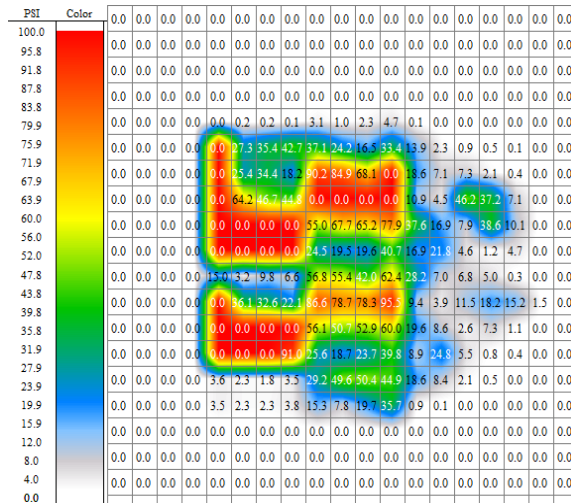


Figure A-31. Super Swamper 38 30 psi 1500 lb.

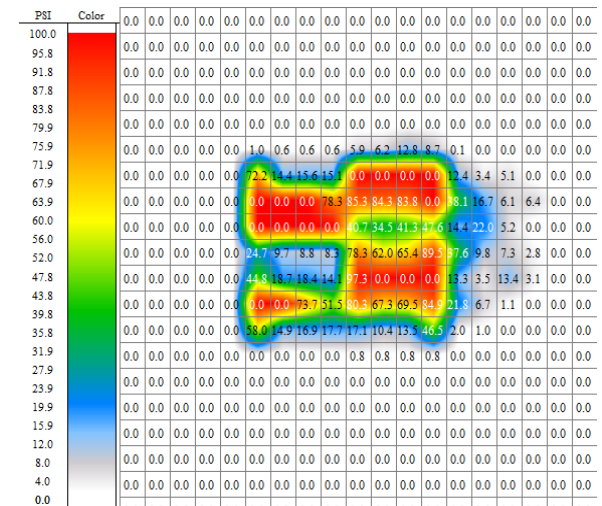
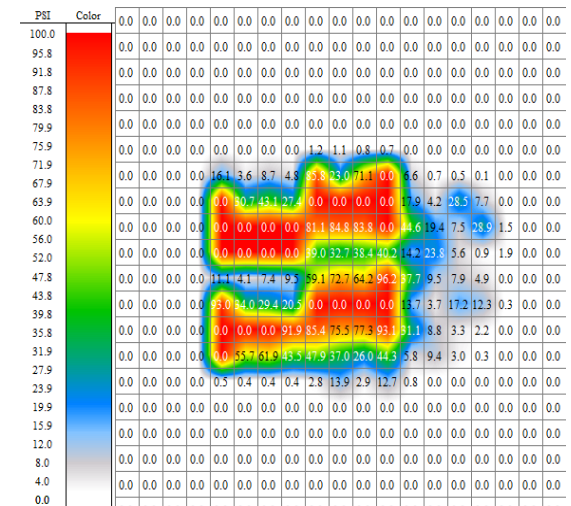


Figure A-32. Super Swamper 38 30 psi 2000 lb.



A.9 Mud Grappler Tactilus pressure maps

Figure A-33. Mud Grappler 18 psi 1500 lb.

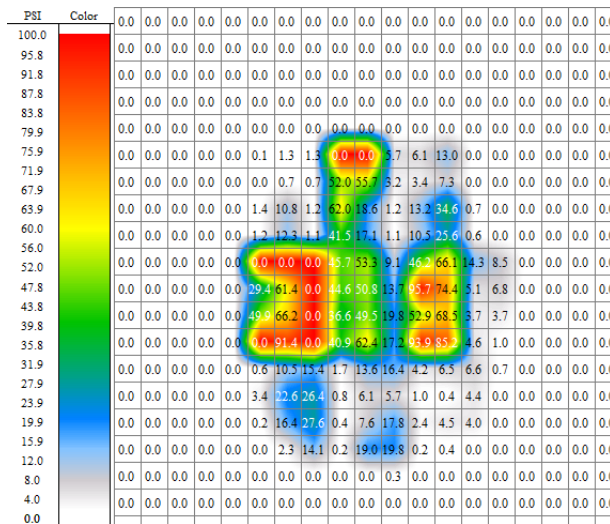


Figure A-34. Mud Grappler 18 psi 2000 lb.

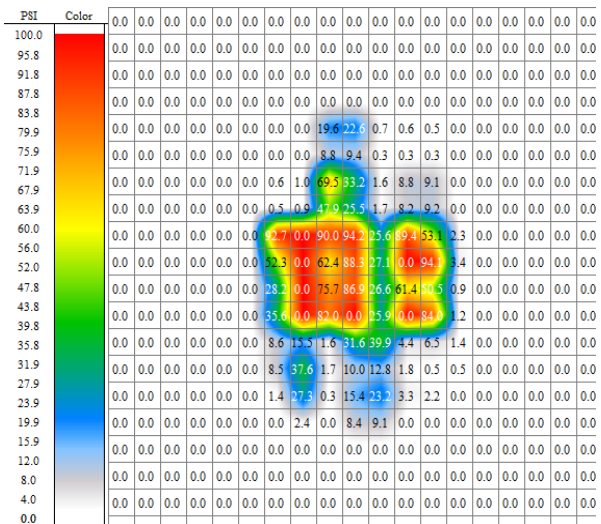


Figure A-35. Mud Grapppler 30 psi 1500 lb.

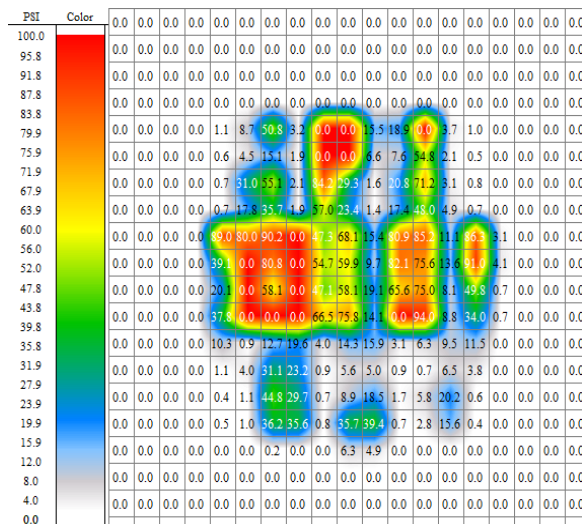
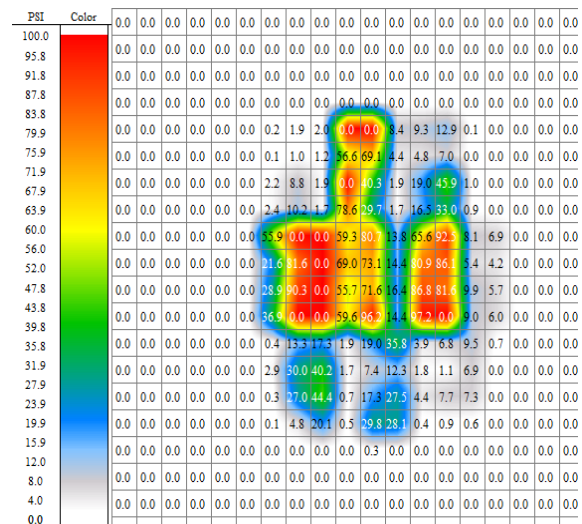
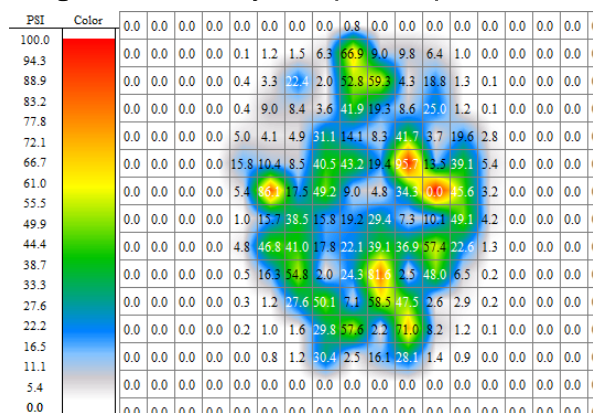


Figure A-36. Mud Grappler 30 psi 2000 lb.





REPORT DOCUMENTATION PAGE

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1. REPORT DATE (DD-MM-YYYY) February 2020		2. REPORT TYPE Technical Report/Final		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE Snow-Road Light-Truck Tire Testing				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Terry D. Melendy Jr., Amelia Menke, Daphnie C. Friedman, and Reed R. Winter				5d. PROJECT NUMBER	
				5e. TASK NUMBER EP-ANT16-22	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Engineer Research and Development Center (ERDC) Cold Regions Research and Engineering Laboratory (CRREL) 72 Lyme Road Hanover, NH 03755-1290				8. PERFORMING ORGANIZATION REPORT NUMBER ERDC/CRREL TR-20-2	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Science Foundation, Office of Polar Programs Antarctic Infrastructure and Logistics 2415 Eisenhower Avenue Alexandria, VA 22314				10. SPONSOR/MONITOR'S ACRONYM(S) NSF	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES Engineering for Polar Operations, Logistics, and Research (EPOLAR)					
14. ABSTRACT The United States Antarctic Program (USAP) anticipates replacing the light-truck fleet in the next 2–5 years and requested a detailed look at the potential tires to be used for ice-shelf work. The USAP fleet management team has worked to reduce the curb weight of potential truck options in an effort to minimize the impact on the snow roads. With current Ford F-350 pickups weighing in at 7840 lb empty and a ground pressure of approximately 17 psi, selecting a lighter truck frame would present major advantages. Similarly, operating the current Mattracks (track system in lieu of tires) installed on some of on the light-truck fleet has run between \$35 and \$50 an hour over the past 6 years, costing the USAP program as much as \$40,000 per season per vehicle. A light truck on tires, for comparison, operated at \$6 per hour at McMurdo Station over the same time span. Following testing of nine different types of tires, this report concludes that a suitable tire replacement for the light-truck fleet is commercially available. The BFGoodrich K2, particularly in the Light Truck 32.8 in. (nominally 33 in.) diameter size (BFG LT33), shows significant advantages at all sizes in this tread pattern.					
15. SUBJECT TERMS Engineering--Cold weather conditions, EPOLAR, McMurdo Station (Antarctica)--Logistics, NSF, Roads--Antarctica, Snow mechanics, Trucks--Tires, Tires--Testing					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (include area code)