TARDEC

---TECHNICAL REPORT---

THE NATION'S LABORATORY FOR ADVANCED AUTOMOTIVE TECHNOLOGY

No. 13691

1994 Quality Improvement Prototype Award

TARDEC

Analysis of an Independent Suspension for Use on Future Medium Tactical Trucks

19960521 005

By Aamodt, Stephen
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WINNER OF THE 1994 FEDERAL QUALITY IMPROVEMENT PROTOTYPE AWARD

U.S. Army Tank-Automotive Research,
Development, and Engineering Center
Detroit Arsenal
Warren, Michigan 48397-5000

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
MAY 96

3. REPORT TYPE AND DATES COVERED
FINAL

4. TITLE AND SUBTITLE
Analysis of an Independent Suspension for Use on Future Medium Tactical Trucks

5. FUNDING NUMBERS

6. AUTHOR(S)
Aamodt, Stephen
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Tank-automotive Research, Development and Engineering Center (TARDEC)
ATTN: AMSTA-TR-R
Warren, MI 48397-5000

8. PERFORMING ORGANIZATION REPORT NUMBER
13691

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
TARDEC University
AMSTA-TR-U
Warren, MI 48397-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Prepared in conjunction with graduation requirements for GMI Engineering & Management Institute

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution Statement A. Approved for Public Release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The independent suspension on the Advanced Technology Demonstrator II (ATD-II) was tested to determine how it compares with the solid axle suspension on the current M923A1. It was found that: 1) the independent suspension weighs more than the solid axle suspension; 2) the ATD-II absorbed less power over test courses simulating real world terrain and 3) the ATD-II absorbed less power due to a shock caused by an abrupt obstacle in the terrain.

14. SUBJECT TERMS
Fully Independent Suspension, Medium Tactical Truck, Technology Demonstrator II

15. NUMBER OF PAGES
64

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

ANALYSIS OF AN INDEPENDENT SUSPENSION FOR USE ON FUTURE MEDIUM TACTICAL TRUCKS

A thesis written at

UNITED STATES ARMY TANK-AUTOMOTIVE AND ARMAMENTS COMMAND

and submitted to

GMI ENGINEERING & MANAGEMENT INSTITUTE

in partial fulfillment
of the requirement for the
degree of

BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

by

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MAY 31, 1996

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DISCLAIMER

This thesis is being submitted as partial and final fulfillment of the work-phase requirements of GMI Engineering & Management Institute needed to obtain a Bachelor of Science in Mechanical Engineering Degree.

The conclusions and opinions expressed in this thesis are those of the writer and do not necessarily represent the position of GMI or the employer, or any of its directors, officers, agents, or employees with respect to the matters discussed.

PREFACE

This thesis is presented to fulfill the requirements necessary for obtaining a Bachelor of Science degree in Mechanical Engineering as specified by GMI Engineering & Management Institute. The purpose of this thesis is to determine if an independent suspension system, specifically the one installed on the Technology Demonstrator II, will offer an improvement over the solid axle suspension system which is currently installed on the M923A1, from which the Demo II is derived. Based on the results obtained herein, a recommendation will be made as whether or not to specify this system for use on the Army's future medium tactical truck class of vehicles. This project is the culmination of my learning experiences both at work and at school. Classes offered by GMI Engineering & Management Institute such as Written and Oral Communication II, Vehicle Design Project and Chassis Design were particularly helpful in compiling this thesis. The preparation and write-up of a previous technical report at TACOM was also very helpful in the organizational aspect of this thesis. The knowledge of suspensions gained at school coupled with the knowledge of technical writing gained both at school and at work was necessary to complete this thesis in the proper manner and in the proper form. Many sources of information were used to generate this document. For a complete listing of all referenced sources refer to the bibliography located after the main body of this work.

The help of many people was necessary to bring this paper to completion. I would like to thank Paul Silbert, team leader for the Demonstrator Truck team for his role as employer advisor and for his insight into the political and technical aspect of the demonstrator truck program and especially the Demo II test vehicle. For his role as faculty supervisor, my thanks goes out to Dr. Pinhas Barak, Professor of mechanical engineering at GMI Engineering & Management Institute in Flint, Michigan, USA. I would also like to thank Mark Mushenski, mechanical engineer in charge of the Technology Demonstrator II, for his support in the technical aspect of the vehicle and for providing other pertinent information regarding the Demo II. Also my thanks is extended to Jennifer Hitchcock, team leader for the Propulsion Products Support team, for allowing me the time to complete this project. Finally, I would like to thank all those people involved with both the building and testing of the Technology Demonstrator II for all their work on this vehicle. Without the help and cooperation of the above mentioned people this report could not have been written.

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I. INTRODUCTION

BACKGROUND INFORMATION

The Tank-Automotive Research, Development and Engineering Center (TARDEC) is part of the United States Army Tank-automotive and Armaments Command (TACOM). TACOM is a United States Department of Defense installation. This U.S. government facility is located in Warren, Michigan U.S.A. The purpose of TARDEC is to support U.S. military forces by providing them the decisive edge in military ground vehicle technology. At TACOM/TARDEC all U.S. Army ground vehicles are supported through their entire lifecycle from the initial concept to support for fielded vehicles.

The TACOM/TARDEC history can be traced back to 1940. This is when the Detroit Arsenal, or tank plant, construction began at the current Warren, Michigan, site. By April 1941 the Detroit Arsenal was producing tanks for the Army. In 1942, while tanks were being produced at the Arsenal, the Tank-Automotive Center was established in downtown Detroit to oversee all military ground vehicle procurement. The Tank-Automotive Center was eventually closed after World War II ended but resurfaced again in 1950 still based in Detroit. In 1954 the first engineering laboratory complex was completed at the Detroit Arsenal's Warren site. This allowed the Army to have a continuing research and development program for its vehicle fleet. Finally in 1964 the Tank-Automotive Center was also moved to the Detroit Arsenal's location thus providing a centralized location for all aspects of military vehicle design, production and procurement. Since 1964 TACOM has grown to its current size though production has since ceased at the tank plant itself. The research and development portion of TACOM has split into a separate subgroup known as TARDEC, while TACOM retains control over all other aspects of the Army's vehicle programs.

TARDEC has a very diverse workforce, consisting of over 1000 associates from the engineering, management, research and clerical fields. TARDEC's associates produce no specific product but rather act in a support capacity to solve problems with, and introduce improvements to any Army ground vehicle and to bring future military ground vehicle concepts into production.

While the tank is the most notable Army vehicle, a large portion of the Army's ground fleet consists of trucks. These trucks are called upon to perform a variety of functions. As the demands placed upon these trucks increase, the trucks must be enhanced enough to meet the challenge. Goals have been set to increase a trucks mobility, increase offroad speed and increase the truck's weight to payload ratio. The suspension system has been targeted as a potential site for improvement in order to allow these trucks to increase their mobility, offroad speed and carrying capacity. This thesis will focus on the advantages and disadvantages of specifying an independent suspension system for use on future medium tactical trucks.

OBJECTIVE OF THE INVESTIGATION

As the Army sets increased goals for performance of tactical trucks, current systems become less able to meet these goals. This necessitates the need to evaluate new technology for possible implementation into future tactical trucks. Technology demonstrator vehicles are used to exhibit future technologies and their application to military vehicles. One of these vehicles, the Technology Demonstrator II (Demo II), is a medium tactical truck exhibiting new technologies available for this class of vehicle. The Demo II is an Army M923A1 five ton tactical truck that underwent modification to incorporate many new technologies. One of the new technologies incorporated into the Demo II is a fully independent suspension system. The independent suspension system fitted to this vehicle was designed by General Motors Military Vehicle Operations. This investigation will provide an evaluation of this independent suspension with regard to its operation on an Army five ton medium tactical truck. In seeking to evaluate this suspension factors such as vehicle top speed, vibration and weight will be considered. A recommendation will also be made as to the usefulness of applying this fully independent suspension system to the Army's future medium tactical truck fleet.

DEFINITION OF TERMS AND CONCEPTS

TERMS	DEFINITION
DEMO II	A prototype truck used to demonstrate existing commercial vehicle technology in a military application
GM-MVO	Acronym for General Motors Military Vehicle Operations

M923A1	Member of the M939 family of vehicles; base vehicle used to create the Demo II
M939	A tactical truck used by the United States Army and a baseline model for other truck configurations including the M923A1
NATC	Acronym for Nevada Automotive Test Center; facility used for Demo II testing
TACOM	Acronym for Tank-automotive and Armaments Command
TARDEC	Acronym for Tank-Automotive Research, Development and Engineering Center
Technology Demonstrator II	Technical name for the Demo II; a vehicle used by the Army to demonstrate new technologies available for use on future vehicles of the medium tactical truck class
WES	Acronym for Waterways Experiment Station; facility used for the Demo II testing

Table 1

SIGNIFICANCE OF THE PROBLEM

United States Army Tank-automotive and Armaments Command

The United States Army Tank-automotive and Armaments Command (TACOM) is responsible for all Army ground vehicles. Therefore, improvements to such vehicles also fall under TACOM's province. Since improvements are TACOM's responsibility then, any made will reflect upon the image of TACOM. Improvements made to Army vehicles will help TACOM achieve its goal of providing the soldiers in the field with the best available equipment to perform their jobs.

United States Army Tank-Automotive Research, Development and Engineering Center

The Tank-Automotive Research, Development and Engineering Center (TARDEC) of the United States Army prides itself in achieving national recognition and awards for its excellence as an engineering center. Projects such as this can provide exposure to help maintain this organization as the top Army research and development center. In addition, undertakings like this evaluation can help TARDEC to achieve the national and worldwide reputation as the leader in military ground vehicle technology.

Research Business Group

The Research Business Group in TARDEC is concerned with, among other things, increasing the mobility of U.S. Army ground forces. By performing a study on an independent suspension the Research Business Group will have accomplished part of its mission by gaining a mobility analysis on a system never before tested on this type of Army vehicle. This will give an indication as to whether the mobility can be increased in future vehicles by fitting them with independent suspensions.

Team Demonstrator Truck

The Demonstrator Truck team of the Research Business Group is concerned with applying existing commercial vehicle technology to applications in the Army's truck fleet. If one of these technologies proves useful it can be incorporated into future vehicles. As part of this effort the Demo II five ton medium tactical truck has been equipped with many new technologies including a fully independent suspension. From tests performed on this vehicle, team Demo Trucks intends to acquire data on the performance of this type of truck using this independent suspension system. From these results and other concerns, such as the vehicle weight and configuration, a recommendation for this type of suspension is to be made, thus allowing team Demo Trucks to achieve an essential part of its mission.

Personal

This thesis is a culmination of my learning experiences at school and of my practical experiences at work. From performing this investigation into the Demo II's independent suspension system I have learned a great deal about an independent suspension, and my ability to compile and organize a technical paper has vastly improved. From this experience, I now have the knowledge to prepare a technical report for any of the tests currently being run or yet to be run at our facilities and present the results in an organized and efficient manner.

SCOPE/LIMITATIONS

This thesis is concerned only with the advantages and disadvantages of an independent suspension system as installed on a M923A1 five ton medium tactical truck. Performance of suspension systems other than the ones installed on the Demo II test vehicle and the M923A1 base vehicle will not be discussed. Results derived from tests conducted on the Demo II vehicle apply to this specific vehicle only. Extrapolations made to other vehicles may present good indications but may not represent how the system will actually function if installed on them.

METHODS FOR INVESTIGATION

In order to obtain the data necessary to present this report, the Demo II had to be put through a series of tests. These tests were field tests, meaning that the testing was not performed in a lab. The vehicle was run under its own power for all of the test results displayed herein. In order to evaluate whether or not the Demo II actually was providing better or worse performance, a baseline was needed to compare it against. Since the Demo II was built from the chassis of a M923A1 vehicle, it was logical that the baseline vehicle be a M923A1. Further, to ensure that the test and results were as accurate as could be, both vehicles ran the same tests at the same time. This guaranteed that terrain and weather conditions would not be different when each vehicle was tested. The testing on the Demo II and on the M923A1 was performed at three different facilities. Initially testing was performed by General Motors Military Vehicle Operations. This testing consisted of verifying proper system operation and physical characteristic determination. Upon completion of this phase of testing, the Demo II test vehicle was delivered to the United States Army Tank-automotive and Armaments Command (TACOM). Once TACOM had taken delivery the Demo II was sent to Waterways Experiment Station (WES) and Nevada Automotive Test Center (NATC) for further testing. The testing performed at these locations was designed to demonstrate the performance of the Demo II. To evaluate the suspension system, the tests of prime importance were those of ride dynamics and abrupt shocks.

PREVIEW

This report is broken up into several sections. Following this section is the conclusions and recommendations section which contains the end results obtained from this investigation. Next, the discussion section provides an in-depth analysis of the information used to obtain the results presented in the conclusions and recommendations section. A bibliography follows with a list of all the sources used to generate this report. The last section of this report is the appendix which contains tables of the data used in this report as well as certain graphical representations of this data.

II. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. Using an independent suspension causes the test vehicle to gain 1744 pounds
2. The Demo II with the independent suspension was consistently able to move faster and absorb less power than the M923A1 on all terrain roughnesses simulated during testing
3. The Demo II with the independent suspension generally performed better during shock testing allowing the Demo II faster movement over abrupt obstacles when compared to the M923A1

RECOMMENDATIONS

Based on the data available, I recommend the Technology Demonstrator II's independent suspension system for use on future medium tactical trucks. The prime reason for this recommendation is that the Demo II, with the fully independent suspension, today meets the Army requirement for the mobility of its tactical vehicles in the year 2010. The goal required by the Army, by the year 2010, is that their tactical trucks can move at a quantified faster speed over terrain of a given roughness. From figure 1 it can be seen that the Demo II, the dashed line, provides much better performance than the current fleet of medium tactical trucks. Most importantly though, the Demo II surpasses the goal set for the year 2010 at virtually all rms ranges falling just short only in the 1.5 rms range. The

Demo II also performed better during shock testing. The Demo II is capable of driving over obstacles in the terrain that cause abrupt shocks while sustaining a higher speed and absorbing no more power than the M923A1.

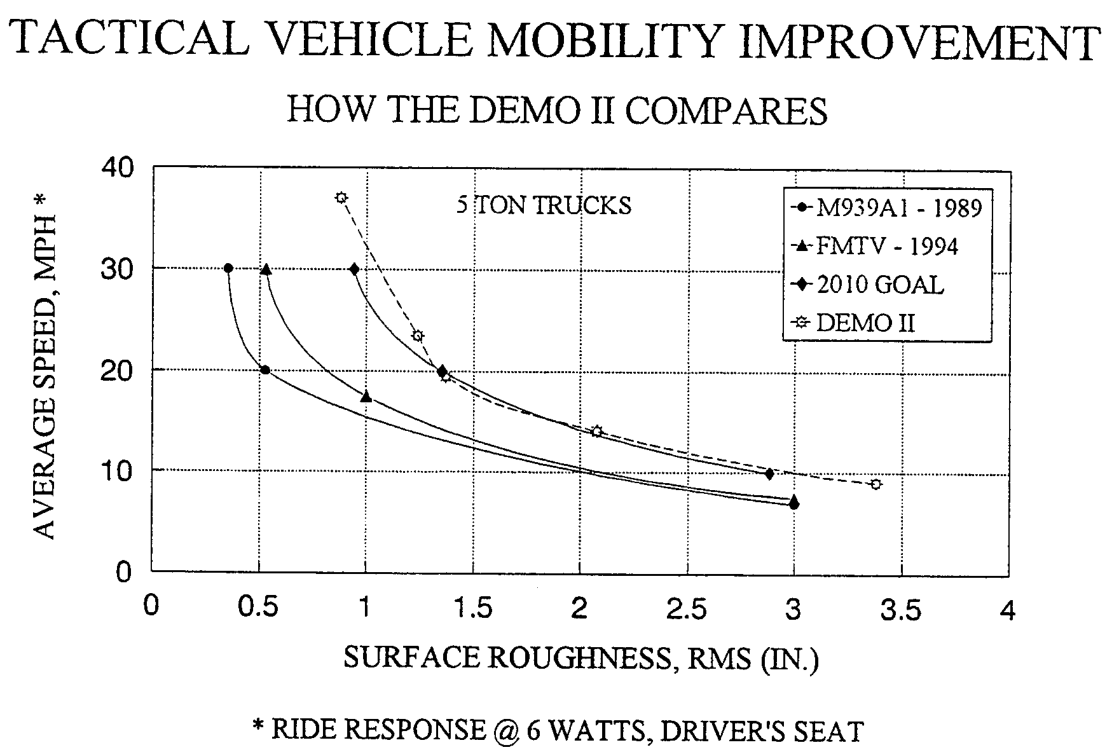

Figure 1

On the downside to this is the weight aspect of the Demo II. The independent suspension added to the Demo II caused the weight of the vehicle to increase by 1744 pounds. This is a sizable increase in weight. The positive aspect though is that GM-MVO has concluded that a potential reduction of 950 pounds could be attained if the independent suspension system was not retrofit into an old vehicle[1]. This is still an increase in the overall vehicle weight.

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[1] Burley, Charles W. and Harold J. Miller, Advanced Technology Demonstrator II (ATD-II) (Pontiac: Military Vehicle Operations, GMC Truck Division, December 1993).

III. DISCUSSION

All vehicles contain a suspension system of some type. The suspension serves a multitude of purposes. It carries the vehicle chassis, body and any load in or on the vehicle. It also serves to shield the occupants from bumps and depressions in the terrain while keeping the tires in contact with the ground. The ability of a tire to keep in contact with the ground is what determines the road handling capability of the vehicle.

M923A1 SUSPENSION SYSTEM

The existing M939 family of vehicles, of which the M923A1 is a member, consists of a solid axle suspension system design. This family of vehicles is also all wheel drive, meaning that every wheel is going to be driven by an input force delivered by a differential. This complicates the solid axle design a bit, but the concept remains the same. A solid axle suspension system can be simplified to be seen as basically a cylindrical or square shaft with wheels attached at both ends. As there is a solid, rigid connection between the wheels on either side, any force that affects one wheel is going to have some effect on the opposing wheel. Every time one of the wheels hits a bump or depression, it transmits a force to the opposite wheel. Because of this, both wheels do not achieve contact with the ground in the capacity in which they should be able to. This movement of a wheel by an input at the opposing wheel can lead to both an increase in the roughness of the ride and a decrease in the handling of the vehicle. Shown in Figure 2 is the front solid axle for the M923A1. This axle is a hypoid, double reduction, single speed unit installed on the underside of the front springs. The differential transmits power from the transfer case to both the left and right axle shafts. At the end of these shafts universal joints permit delivery of power to wheels under all conditions. Based on the drawing of this axle, it is easily visible as to how the movement of one wheel can affect the movement of the other.

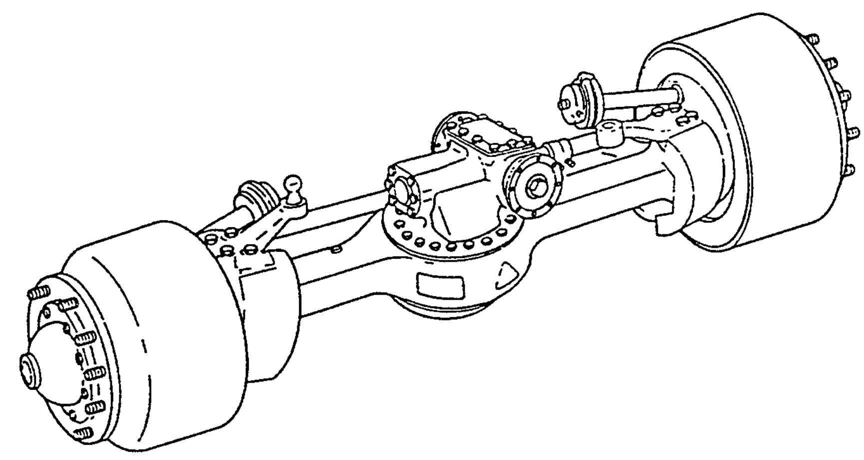

Figure 2 - M923A1 Solid Front Axle

The two rear axles in the M923A1 are also solid axles using leaf springs. Both rear axles are mounted in tandem, meaning the axles are paired and positioned close to one another. The axles use hypoid gearing in a double reduction single speed unit to deliver power. This power is obtained by the differentials from the propeller shaft and transmitted to both the left and right axle shafts. Since the rear wheels are connected together with solid axles, in a little more complicated yet similar fashion to the front wheels, the movement of one wheel will have an effect on the opposing wheel as well. Figure 3 shows the configuration of the rear axles. This suspension system on the

M923A1 allows both the front and rear of the vehicle to be bounced around as various tires hit depressions or bumps in the terrain.

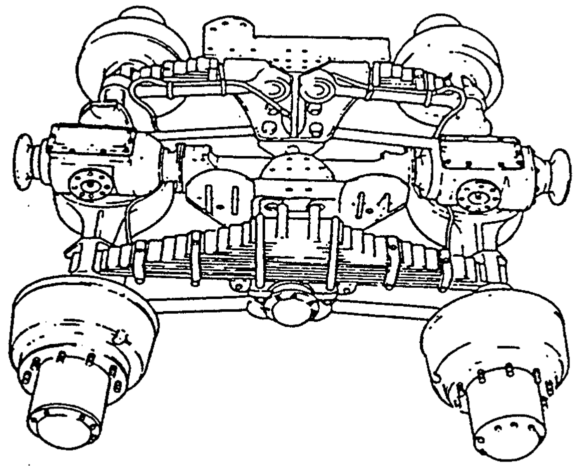

Figure 3 - M923A1 Solid Rear Axles

ARMY TACTICAL VEHICLE GOALS

The Army has set goals for improvements in future tactical wheeled vehicles. One of these goals, mobility improvement, has particular merit here. The major obstacle to increasing the speed of a vehicle over rough terrain is the amount of vibration the operator of the vehicle can handle. Six watts has been determined as a reasonable human tolerance limit for absorbed power[2]. Therefore, it is necessary to increase a vehicle's speed without increasing the amount of power a vehicle is absorbing due to terrain roughness. Figure 4 shows average vehicle speed versus surface roughness for past and present vehicles and the goal for future vehicles. From this it is visible that speed has been increasing over a

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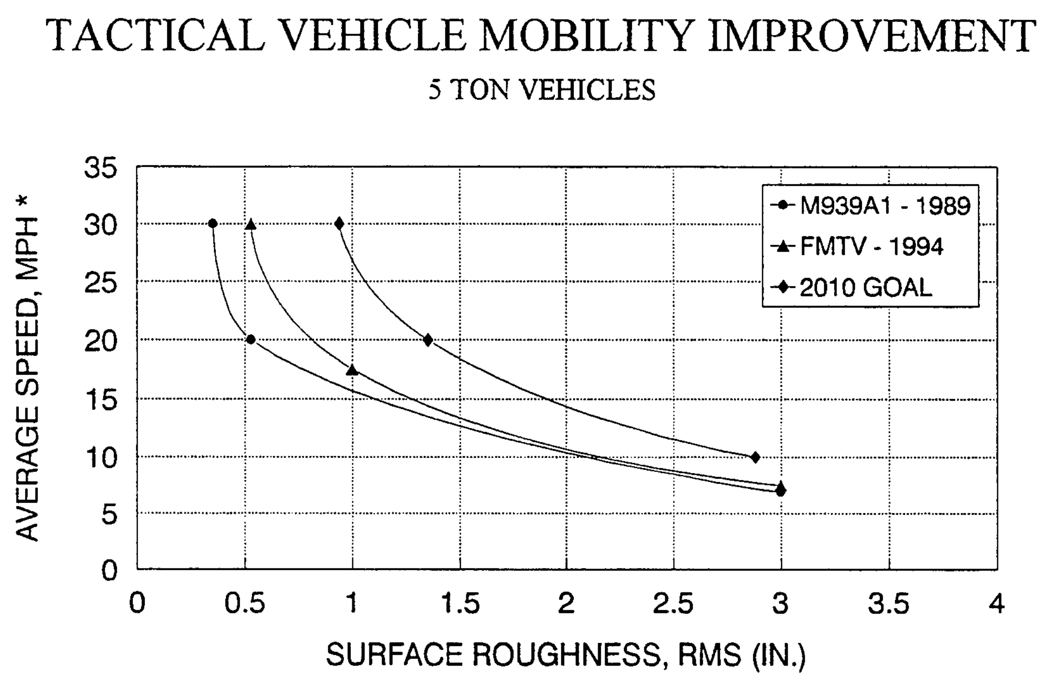
[2] Pradko, F.; Lee, R.; and Kaluza, V. "Theory of Human Vibrational Response." (presented at the Winter Annual Meeting and Energy Systems Exposition of the American Society of Mechanical Engineers, New York, 1966

given roughness through the years. The goal the Army has set for 2010 necessitates the need to improve the mobility of future medium tactical trucks.

Changing the current suspension system is one way in which this problem has been approached. The current solid axle suspension system in the M923A1 has been tested on courses of varying roughness to determine the speed versus the amount of absorbed power. It is the object of these tests to determine whether a fully independent



* RIDE RESPONSE @ 6 WATTS, DRIVER'S SEAT

Figure 4

suspension system installed on the Demo II, and tested over the same courses, reduces can reduce the amount of vibration an operator feels at a given speed. If this can be achieved, a vehicle (medium tactical truck for this report) will be able to move faster over a given terrain without the operator experiencing a ride with more vibration than is acceptable by Army standards.

Another area of improvement the Army is seeking is a decrease in a truck's curb weight to payload ratio. In other words, the Army desires to decrease a vehicle's weight while maintaining the ability to carry a set maximum payload. This can be accomplished by increasing the payload capacity and maintaining current vehicle weight, decreasing vehicle weight while maintaining current payload capacity, or by a combination of both increased payload capacity and decreased vehicle weight. The optimum design would be

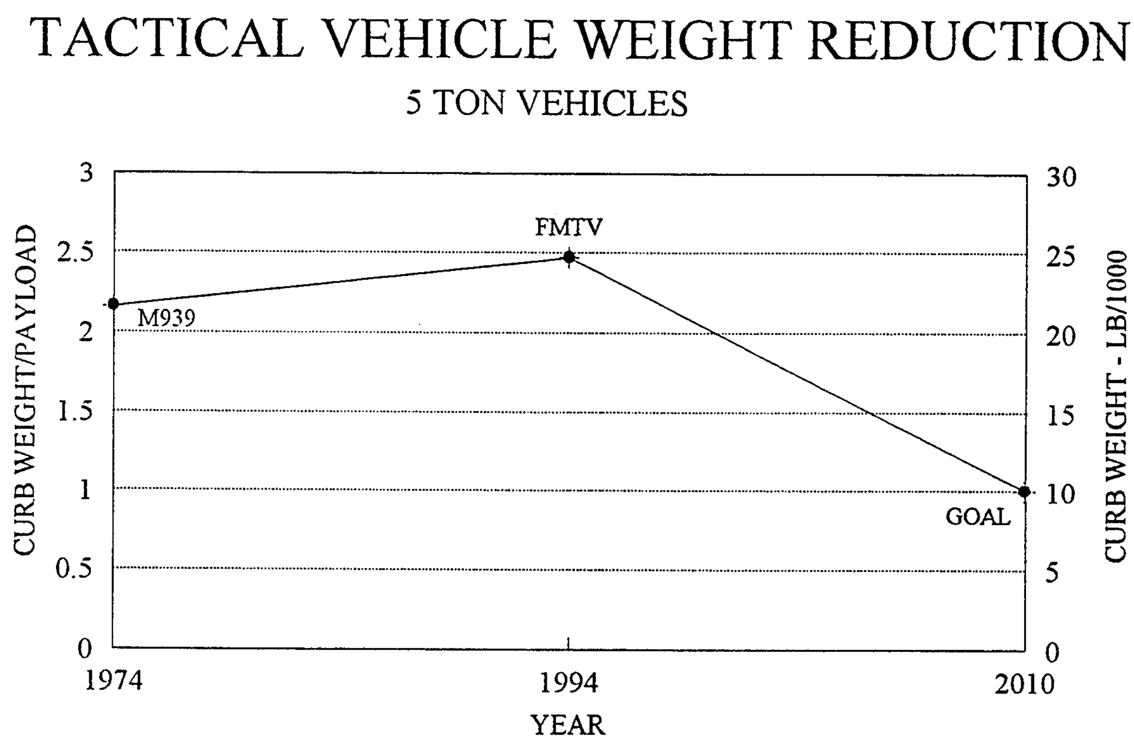


Figure 5

to decrease the vehicle's weight by roughly half and be able to carry its own weight in cargo. The goal as compared to current and future trends can be found in figure 5. To evaluate the Demo II in this category the weight of the installed fully independent suspension system must be compared to the weight of the standard solid axle suspension system in the M923A1.

TECHNOLOGY DEMONSTRATOR II

In an effort to evaluate new technology available for potential use on future Army tactical trucks, advanced technology demonstrator vehicles have been built encompassing various available new technologies. The Technology Demonstrator II is one of these vehicles built to demonstrate new technology available for the Army's medium, 5-ton, tactical trucks. The technology demonstrated today on the Demo II shows the potential for standard technology on future vehicles in the medium tactical truck class. The Demo II project was started in 1988 as a joint venture between the U. S. Army Tank-automotive and Armaments Command and General Motors Military Vehicles Operations. The object was, and still is, to determine the feasibility of applying any number of the new technologies incorporated in the Demo II into future medium tactical trucks put in service by the U.S. Army. The Demo II was built on the chassis of a vehicle in the M939 family, more specifically the M923A1 5-Ton truck. The completed Demo II test vehicle is shown in figure 6 and figure 7. GM-MVO initially built the vehicle and then tested it to make sure that all the components and systems were functioning properly. Upon completion of this phase of testing, the vehicle was delivered to TACOM for further testing to be conducted at various testing facilities with suspension tests to be run at the Nevada Automotive Test Center and at Waterways Experiment Station.

Many new components and features have been built into the Demo II to demonstrate the state-of-the-art technologies available for application to the Army's medium tactical trucks. Some of these include a new lightweight 6.6 liter 6-cylinder turbocharged diesel engine, a 7-speed automatic transmission with electronic control, a

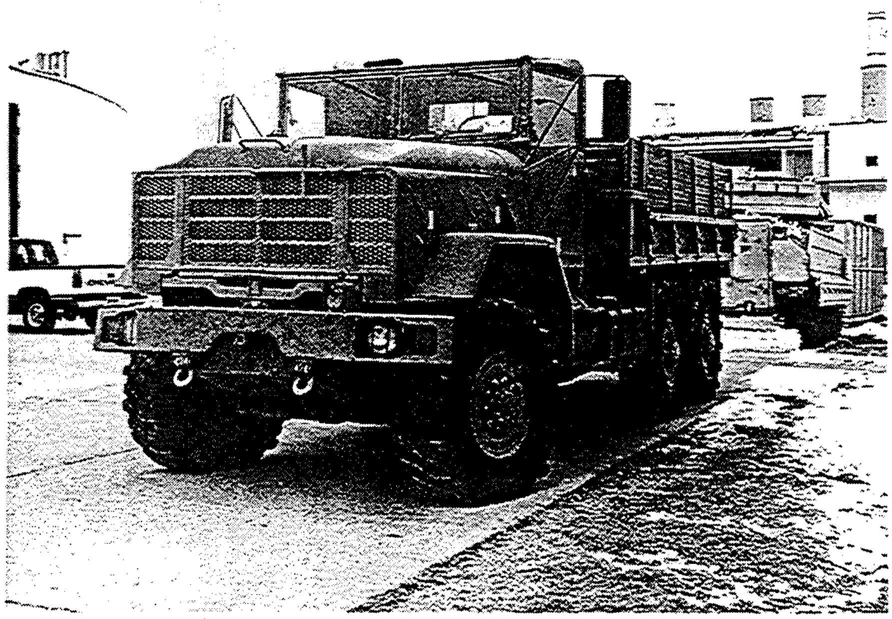


Figure 6 - Demo II, 3/4 View

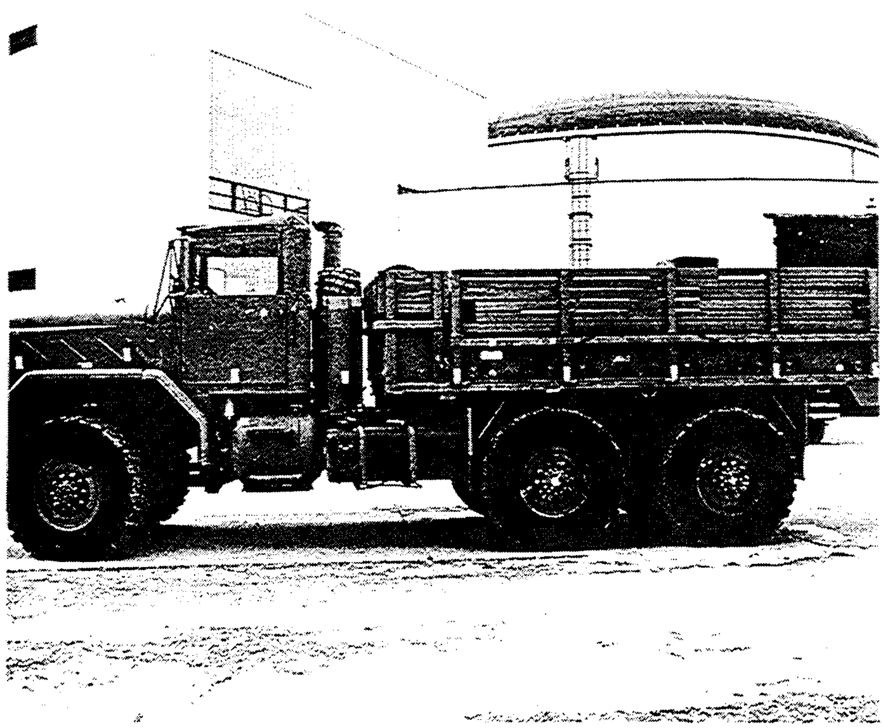


Figure 7 - Demo II, Left Side View

fully independent suspension system, an anti-lock braking system, automatic traction control and an automatic clean-in-place air cleaner with a 200-hour filter element. Though the Demo II presents a wide assortment of new systems to study, the main focus of this report is on a determination of the usefulness of specifying an independent suspension for use on the Army's future medium tactical trucks. Therefore, this paper will only deal with the independent suspension system, and testing related to it, with reference to the other vehicle components only as necessary.

Demo II Suspension System

The Technology Demonstrator II's independent suspension system was designed and built by General Motors Military Vehicles Operation (GM-MVO). The suspension system design is double A-arm design with one Matthew Warren coil spring and dual General Kinetics shock absorbers resting on the top arm at each wheel. Also used are Rockwell independently suspended single speed wheel end hub reduction axles. The tires used are Michelin XML super single 14.00R20 radials. Figure 8 shows the final configuration of the above components as installed in the Demo II test vehicle.

An independent suspension performs the same general tasks as does a solid axle suspension system. Like the solid axle system, it must support the vehicle weight while insulating the driver and vehicle contents from terrain hazards such as bumps and holes. While doing this it must maintain traction at the wheels in order to propel the vehicle forward. The difference between a solid axle design and an independent design is in how the above tasks are accomplished. Unlike a solid axle design, an independent suspension design has an axle that is not one solid piece. The axle does not bear the force of the

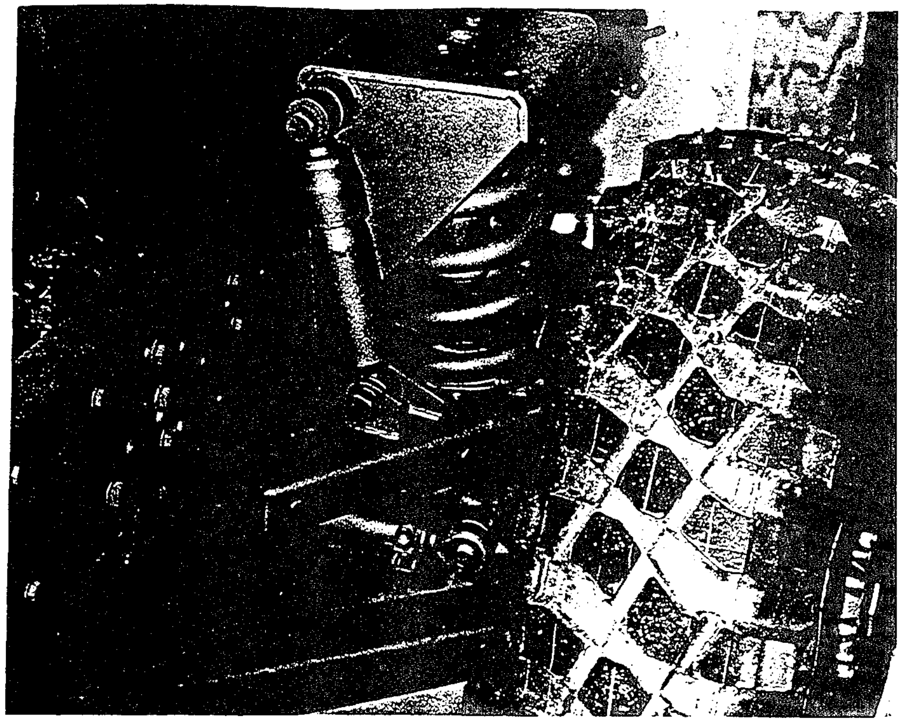


Figure 8 - Demo II Independent Suspension During Build

vehicle any longer. That is left to the rest of the suspension system. There is a separate suspension portion at each wheel, consisting of two sets of A-arms with a coil spring and two shock absorbers. The arms, or the parts that attach the wheel to the frame, are called A-arms simply because they resemble the letter A in their looks. From figure 9 it can be seen that there is both a lower and an upper A-arm at each wheel. The arms are attached to the top and bottom portion of the wheel, and to a lower and upper portion of the frame of the vehicle. Both the upper and lower A-arms pivot at the wheel and at the body so that the wheel can drop down when it hits a hole or move up when it hits a bump while keeping the tire as perpendicular to the surface of the ground as possible. The spring, for the Demo II, is located on top of the upper A-arm. This provides for lifting the vehicle and keeping it off the ground. It also acts to help absorb some of the roughness of the

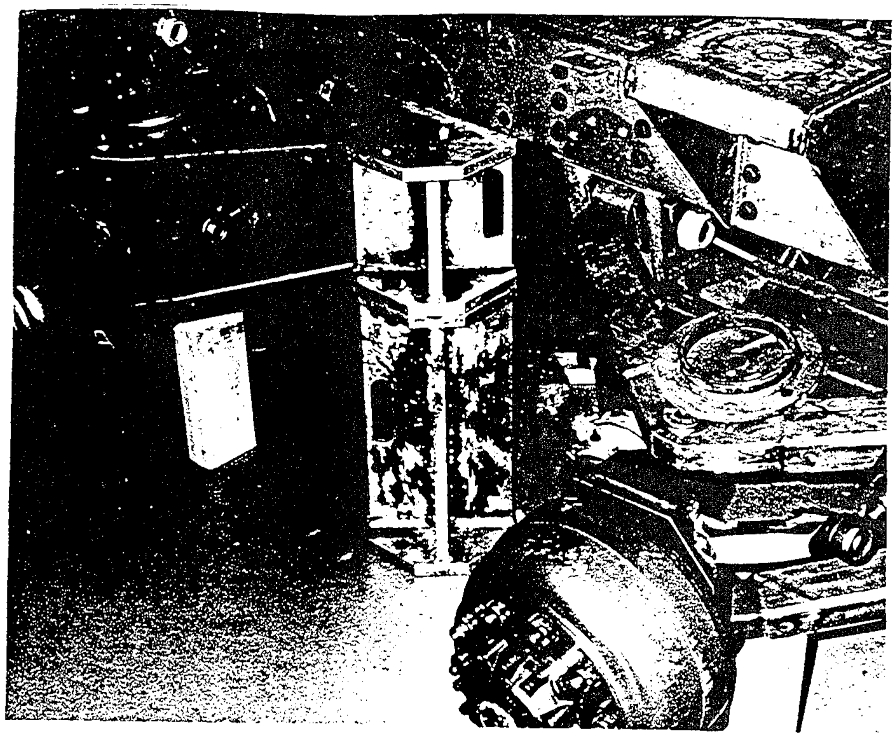


Figure 9 - Demo II Rear Suspension During Build

terrain by smoothing out the vehicle movement in the up and down direction. This occurs when the spring stretches or is compressed after hitting a hole or bump so that the passenger compartment is not pulled or pushed in one direction or the other as much. The shock absorbers are located on either side of the spring and are there to shield the vehicle body from feeling what the wheel feels. It performs its function by controlling the spring so that it does not keep bouncing up and down after being displaced the first time. They act to slow the movement of the vehicle in the upward or downward directions, and also to stabilize the passenger compartment quickly after hitting an obstacle. Figure 10 shows the layout of the spring and the shock absorbers as installed on the Demo II.

The overall design of an independent system lets one wheel hit a bump and raise up while the opposing wheel stays perpendicular to the surface. This ability lets the

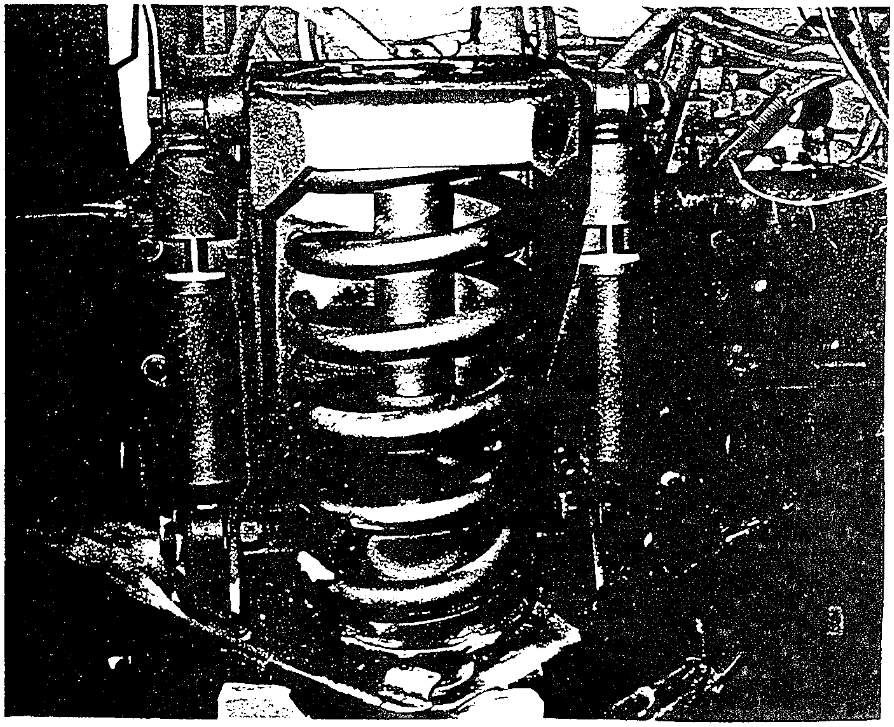


Figure 10 - Spring and Shock Absorbers on the Demo II

unaffected wheel and tire maintain full contact with the ground without being bounced around as a result of the other wheel's movement, while at the same time giving the affected wheel and tire the ability to move with the terrain to achieve better contact. As handling is influenced by how well a wheel is in contact with the ground, better ground contact provides for better handling. Also, as both wheels will be bouncing around less since they are not physically connected, the amount of vibration to the passenger compartment should be reduced. Theoretically then, this should allow a vehicle to travel faster while maintaining the same vibrational level that a solid axle system would induce at a slower speed.

Demo II Alterations

The base vehicle, a M923A1 5-ton medium tactical truck, was modified and retrofitted to allow the application of the new suspension system along with all the many other new technologies to be included on it. As this was done, some external changes occurred in the vehicle's dimensions to allow these new technologies to fit. The vehicle increased in length by 3.5 inches to 311 inches. The height increased by 4.8 inches to 116.7 inches. The width decreased, though, to 96.8 inches from 97.5 inches. One of the more important differences is the amount of ground clearance. The base M923A1 vehicle had an under axle clearance of only 11.5 inches. The Demo II, by installing the independent suspension, has increased the under axle ground clearance by 8.0 inches to a total of 19.5 inches. Some external dimensional changes also occurred that have the potential to affect the vehicle's mobility. The front and rear track of the Demo II increased, the front by 4.5 inches, and the rear by 7.5 inches. This has the potential to provide better handling when the vehicle is turning.

Factors other than just vehicle dimensions were affected when the vehicle was retrofitted. The weight of the vehicle and the distribution of this weight has also changed. By adding the independent suspension to a M923A1 the unsprung weight was reduced by 1732 pounds. In comparison though, the total sprung weight increased by a total of 3367 pounds. This shows a mean increase in the weight of the vehicle of 1635 pounds. Some of the new components allowed a weight reduction while other components caused a significant increase in vehicle weight.

Since the suspension system is of prime concern, its solitary affect on the total vehicle weight will be discussed. The axles installed on the Demo II were lighter than those on the M923A1 causing the vehicle weight to reduce slightly, 150 pounds less for the front axle and 170 pounds less for the combined rear axles. The suspension on the front and rear of the vehicle caused an increase in weight. The front suspension increased by 734 pounds while the rear increased by 700 pounds. The Demo II also has crossmembers and stiffeners, that the M923A1 lacks, to provide better stability for the vehicle. These components added more weight to the Demo II by way of 630 pounds. The net increase due to the suspension system as a whole turns out to be 1744 pounds.

GM-MVO concluded that an independent suspension system will weigh more in a retrofit program. It is their belief that there is potential for weight reduction, assuming the vehicle were to be built from scratch and not retrofit[3]. It is felt the this reduction would amount to 950 pounds. This potential weight reduction is still insufficient to offset the weight gain by using an independent suspension. The suspension system would gain 794 pounds. This would cut the weight gain in half though as compared to the current retrofit design on the Demo II.

There are a few other alterations between the Demo II and M923A1 as well. The Demo II itself had its configuration changed during the testing phase. This involved increasing the front spring rate to 1250 pounds per inch and decreasing the tire inflation pressure. For a tabular comparison of some of the changes potentially affecting vehicle performance during testing at WES please refer to appendix A.

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[3] Burley, Charles W. and Harlod J. Miller, Advanced Technology Demonstrator II (ATD-II) (Pontiac: Military Vehicle Operations, GMC Truck Division, December 1993).

Independent Suspension System Cost

Another important factor to consider is how much this independent suspension system will cost. An independent suspension system is more complex than a solid axle system. Therefore, an independent system will be more costly than a solid axle system. Under this premise, the Demo II independent suspension is likely to cost more than the solid axle system on the M923A1.

For the Demo II test vehicle though, all the parts used in the suspension system were fabricated as one time prototype parts. This eliminates the ability to reduce cost by mass production whereby material costs could be reduced by buying in bulk, and overhead costs could be distributed between the many produced parts. Therefore, for the Demo II, a valid comparison cannot be made between the cost of the old system versus the cost of the new system as the processes used to produce both systems vary greatly.

WATERWAYS EXPERIMENT STATION TESTING

During the period of January 1992 through April 1992 the US Army Corps of Engineers Waterways Experiment Station (WES) conducted mobility tests to compare the Demo II with its present day counterpart, the current M923A1. Again, during the period of February 1994 through May 1994, more testing was performed by WES on the same vehicles. The purpose of these studies was to evaluate new technologies such as an anti-lock brake system, automatic traction control system and a fully independent suspension system to determine the performance of these systems as installed on an Army medium tactical truck.

The curb weight of the M923A1 and the Demo II are not close enough to allow for a valid direct comparison. This could lead to some inconsistencies in the test results when comparing the two vehicles. It was decided by TACOM and WES personnel that in order to more accurately compare the two vehicles that the weights would have to be more evenly matched. To this end weight was added to both vehicles. Five tons was added to the M923A1 test vehicle while only four tons was added to the Demo II. This distribution of additional weight allows the two vehicles to have gross weights that are very close with 32,830 pounds for the Demo II and 32, 530 pounds for the M923A1. The tests performed in 1992 used these test weights. By 1994, configuration changes had altered the Demo II weight and the new test weight became 33,190 pounds.

Ride Dynamics Testing

All of the following results were obtained at Waterways Experiment Station, LeTourneau test site, using five different courses. Those courses were 1,4,5,6 and 7. Each course is 500 feet long and constructed to simulate amplitude distributions and corresponding surface roughness levels generally found in real world terrain. Course 1 is considered smooth. Courses 4 and 5 are considered moderately rough. Courses 6 and 7 are considered rough. Roughness is measured based on the detrended root-mean-square (rms) of elevation survey data method. Values of roughness for each of the test courses during the 1992 and 1994 testing are found in table 2.

Ride quality over rough terrain is presently expressed in terms of absorbed power at the driver's seat. Absorbed power is defined as the rate at which vibrational energy is absorbed by a human body. Absorbed power was established as a ride severity criteria

Course	Surface Roughness (rms), Test 1, 1992	Surface Roughness (rms), Test 2, 1994
1	0.88	0.81
4	1.37	1.28
5	1.24	1.16
6	2.08	2.03
7	3.38	3.38

Table 2 - Roughness Values for Ride Dynamics Courses

through laboratory tests at TACOM[4]. Field tests performed on various vehicles since have confirmed that absorbed power in the vertical direction at the driver's seat agrees well with the driver's opinion of ride quality and generally appears to be the best parameter describing ride performance. Six watts of vertical absorbed power has been determined to be the reasonable human tolerance criteria and is currently used to designate the top speed at which the driver will operate the vehicle for extended periods of time. From field tests it has been shown that drivers will subject themselves to more than six watts for short periods of time, but no more than six watts for extended periods.

The results that follow are compared based on two criteria, speed and absorbed power. The LeTourneau test site was used to test both the Demo II and the M923A1 for the 1992 testing. The Demo II, during this testing phase, was equipped with front springs with a stiffness of 750 pounds per inch and rear springs with a rate of 1250 pounds per inch. The inflation pressure on the tires was 35 psi all around. The gross vehicle weight for this phase of testing was 32,830 pounds. Both vehicles were run on the same test

[4] Pradko, F.; Lee, R.; and Kaluza, V. "Theory of Human Vibrational Response." (presented at the Winter Annual Meeting and Energy Systems Exposition of the American Society of Mechanical Engineers, New York, 1966).

tracks to allow for easy comparison between them. Many tests were conducted for each vehicle at varying speeds on the 500 feet tracks, going both from the 0 foot mark to the 500 foot mark and from the 500 foot mark back to the 0 foot mark.

In 1994 testing was again performed on the Demo II. This time the front springs were heavier and stiffer with a spring rate matching the rear at 1250 pounds per inch. The inflation pressures for the tires were changed. For typical cross country driving the front tires would be at 32 psi while the rear tires were at 26 psi. The weight had also increased to a testing weight of 33, 190 pounds. The 1992 test is dubbed "Test 1" and the 1994 test as "Test 2" for this report. The complete data obtained for both tests of the Demo II and the M923A1 can be found in appendices B and C respectively.

The Demo II and the M923A1 differ drastically in their speeds attainable on the smooth test track. The M923A1 with its solid axle suspension system does not come close to performing as well as the Demo II with its independent suspension on course 1. The Demo II shows its vast mobility improvement over the M923A1 most noticeably at higher operating speeds. Figure 11 displays a graph of all of the test points taken to allow an easier visualization of the operation of these two vehicles. The Demo II with its independent suspension system absorbs significantly less power from the road surface at speeds above 10 miles per hour. Course one, as explained before, is considered smooth for testing purposes. The solid line is representative of the M939 family of vehicles as they exist today. The M923A1 reaches the 6 watts absorbed power criteria at roughly 15 miles per hour. Both dotted lines represent the Demo II test vehicle. The test run in 1992 is signified by the sunburst marker while the test run in 1994 is signified by the black dot marker. On the smooth course there is almost no difference in the performance of these

Absorbed Power vs Vehicle Speed

Course 1, 0-5

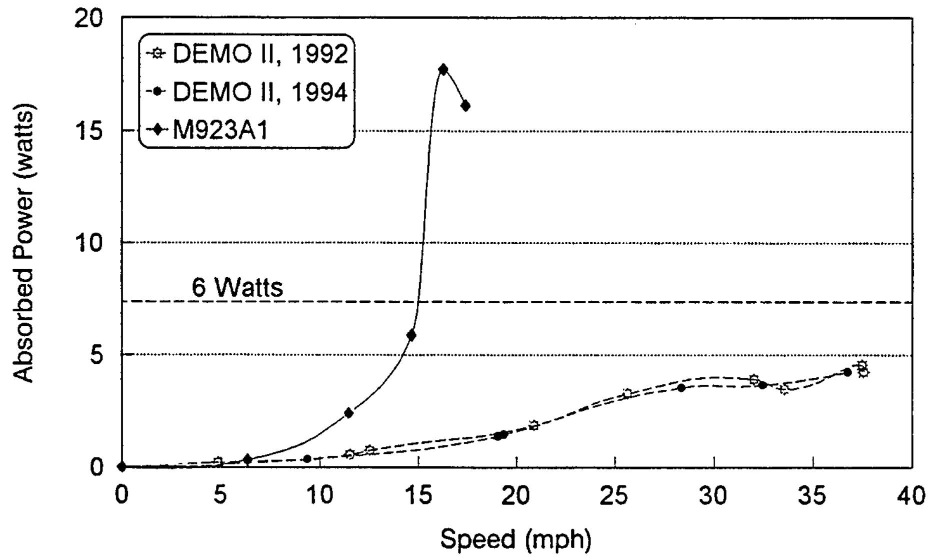

Figure 11

two configurations, though both configurations offer significant improvement over the M923A1 test vehicle. Both Demo II configurations, at 15 miles per hour, have only attained just over one watt of absorbed power. In fact throughout the test, both configuration never exceeded the 6 watts of absorbed power criteria. From the data available the Demo II configurations show an increase of more than double the usable speed of the M923A1 on a smooth surface.

Course five is considered a moderately rough course. On this course, both vehicles eventually exceeded the six watts of absorbed power criteria. As shown in figure 12, the M923A1 follows a somewhat exponential curve with the absorbed power rising rapidly as vehicle speed increases. It proceeds to cross the six watt mark while achieving only around 13 miles per hour. Both Demo II test configurations proceed along virtually the same path with a much more linear manner. Both cross the criteria limit at nearly 23 miles per hour. This translates to more than a 75% improvement in the mobility of the vehicle. Though on this type of terrain both vehicles exceed the 6 watt criteria for absorbed power, the Demo II shows excellent performance even above this level. As

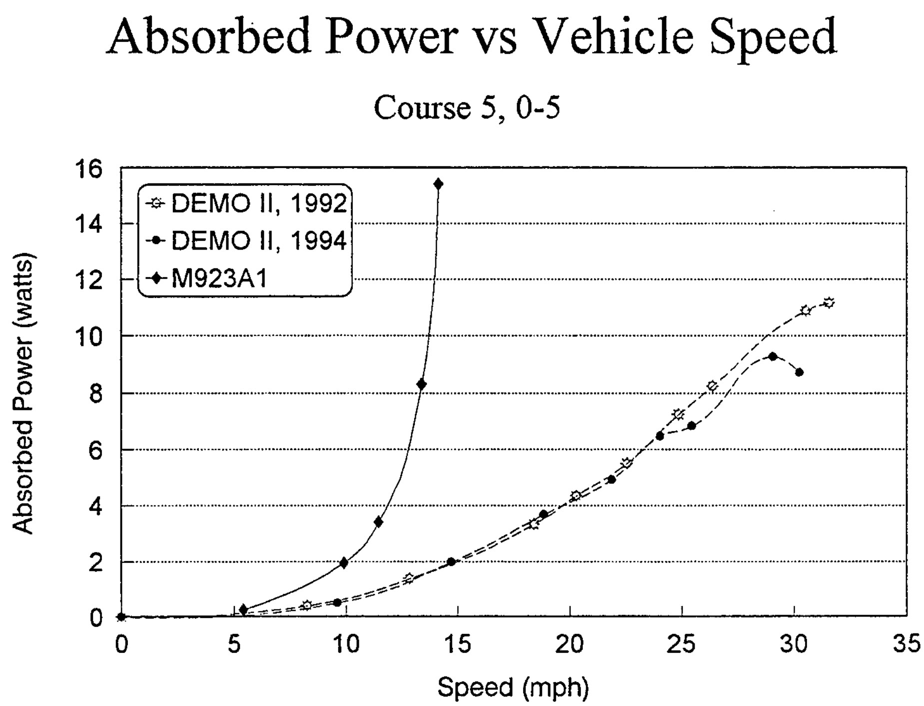

Figure 12

noted before, drivers will subject themselves to higher power levels, but only for limited periods. Take, for example, 10 watts of absorbed power. The M923A1 can only go around one mile per hour faster while absorbing the four extra watts of power necessary to go that fast, while the Demo II can go roughly six miles per hour faster with the same extra four watts of power. This is around a 100% improvement in vehicle speed for short duration travel. At acceptable power levels, the noticeable increase in performance is seen after the vehicles reach 6 miles per hour, and the performance gap increases dramatically thereafter.

Course 7 is considered to be a rough terrain course. This type of course is the most difficult for vehicles to navigate, hence the slower operating speeds. Both vehicles must move at low speeds on this course but the Demo II, with its independent suspension, does provide some improvement, most notable during the second test of the Demo II with the stiffer springs installed. The Demo II configurations perform much better even considering these are low speeds. It needs to be noted though that while the Demo II configurations did achieve higher operating speeds, none of the tested vehicles were able to achieve ten miles per hour while adhering to the absorbed power criteria. Course seven test results as shown in figure 13 are typical of speeds attained over rough terrain in a real-life situation. As can be seen from viewing this graph, there is improvement when operating the Demo II in its original configuration. This amounts to only two miles per hour faster, but even though the speed increases by only a small measure, this translates to

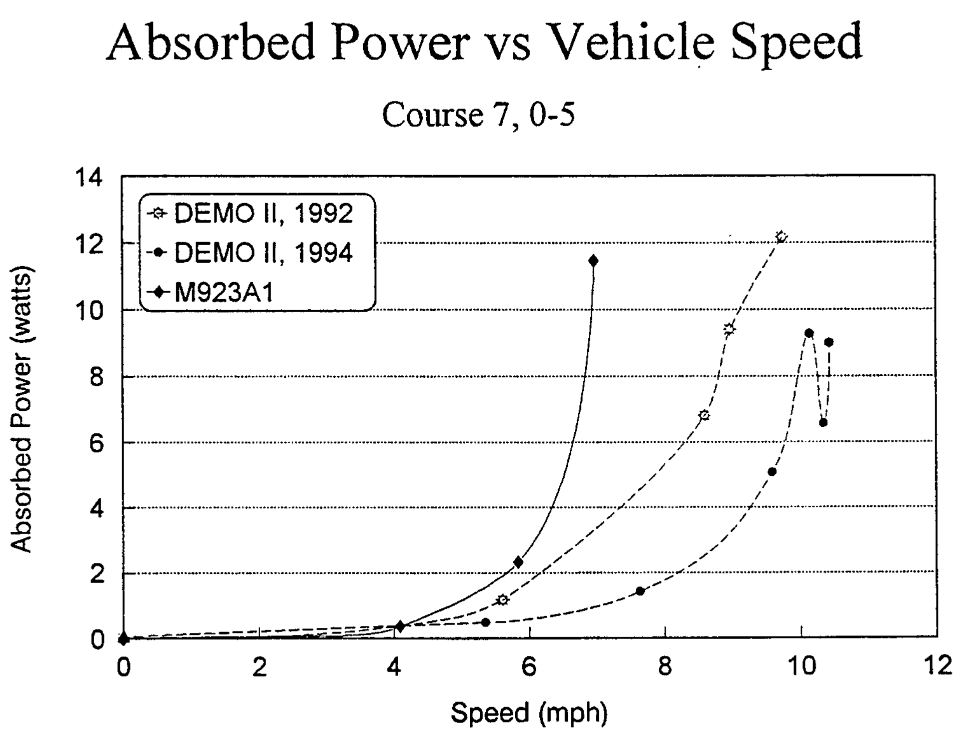

Figure 13

a 30% improvement in the mobility of the vehicle at 6 watts of power absorbance. The second Demo II configuration offers an improvement amounting to almost three miles per hour. This generates an improvement of close to 50% more speed at the criteria limit. On this rough course, exceeding the 6 watt criteria provides only minimal improvement in the speed difference between the tested vehicles.

The figures displayed previously are just a sample of those generated from the ride dynamics testing performed at WES. For a complete graphical comparison of the performance of the M923A1 and both configurations of the Demo II on all test tracks and in both directions refer to Appendix D.

Shock Testing

In addition to the ride dynamics portion above, shock testing was also performed on the Demo II at WES. A shock test is used to determine how much energy is being absorbed by the driver when the vehicle encounters an abrupt obstacle in the road. Since Army vehicles are designed for off-road travel, where there is little, if any, paved surface, this test becomes increasingly important. Results from past studies indicate that the height of the obstacle encountered is a good measure of characterizing it. As with the ride dynamics testing, a criteria has been specified as a limiting agent to vehicle speed. For purposes of an abrupt shock, 2.5 g's in the vertical direction is set as this criteria.

The two configurations of the Demo II, with and without the stiffer springs, were run along with the M923A1 baseline vehicle. These vehicles were run over four different obstacle heights consisting of six, eight, ten and twelve inches. The obstacles used for this testing were steel and in the form of a half-moon. The M923A1 was only tested on the smaller three of these obstacles. Statistical results for the tests performed on the Demo II and the M923A1 can be found in appendices E and F respectively. Graphical results showing the performance comparison between the M923A1 and both Demo II configurations are presented in appendix G. The testing performed shows that the Demo II configurations were able to navigate the obstacles while experiencing less vertical acceleration than the M923A1. The Demo II with the stiffer springs did not provide a consistently better or worse overall performance on all of the obstacles. However, on the higher two obstacles the test 2 configuration, with the front spring rate at 1250 pounds per inch, did perform somewhat better than the test 1 configuration with the front springs at 750 pounds per inch.

In comparing the Demo II configurations to the M923A1 in this test, the general trend shows that the Demo II configurations can hit the same obstacles as the M923A1 while absorbing less power from movement in the vertical direction. The Demo II does not necessarily perform better at all speeds though. Rather, for some of the obstacles the Demo II performance was better at lower speeds while at others the performance was better at higher speeds. Unlike the ride dynamics testing, there does not appear to be an increasing gap between the M923A1 and the Demo II as vehicle speed increases.

NEVADA AUTOMOTIVE TEST CENTER TESTING

At NATC ride dynamics testing on the Demo II was performed. As with the WES testing, a M923A1 baseline vehicle was also tested. For the testing performed at NATC the Demo II still had the springs with a rate of 750 pounds per inch on the front versus the later change increasing them to 1250 pounds per inch to match the back springs.

Preliminary results made available indicate that the Demo II performed better than the M923A1 that it was tested against. Appendix H contains the equations and best fit curves obtained from testing at NATC. Actual data has not been made available at this time. The testing performed at NATC was done under different vehicle conditions than the testing performed at WES. The Demo II, when run at NATC, was loaded with five tons of weight, versus four tons at WES. As five tons is the stated carrying capacity of a vehicle of its class this is viewed as a very practical test. Unlike WES testing, the M923A1 baseline vehicle weight was not adjusted to match that of the Demo II. This made the Demo II roughly 2000 pounds heavier when tested at NATC while also carrying a load that is more typical of a real world situation. Though not tested under the same vehicle conditions as at WES, the results obtained at NATC provide verification of results obtained during the testing at WES.

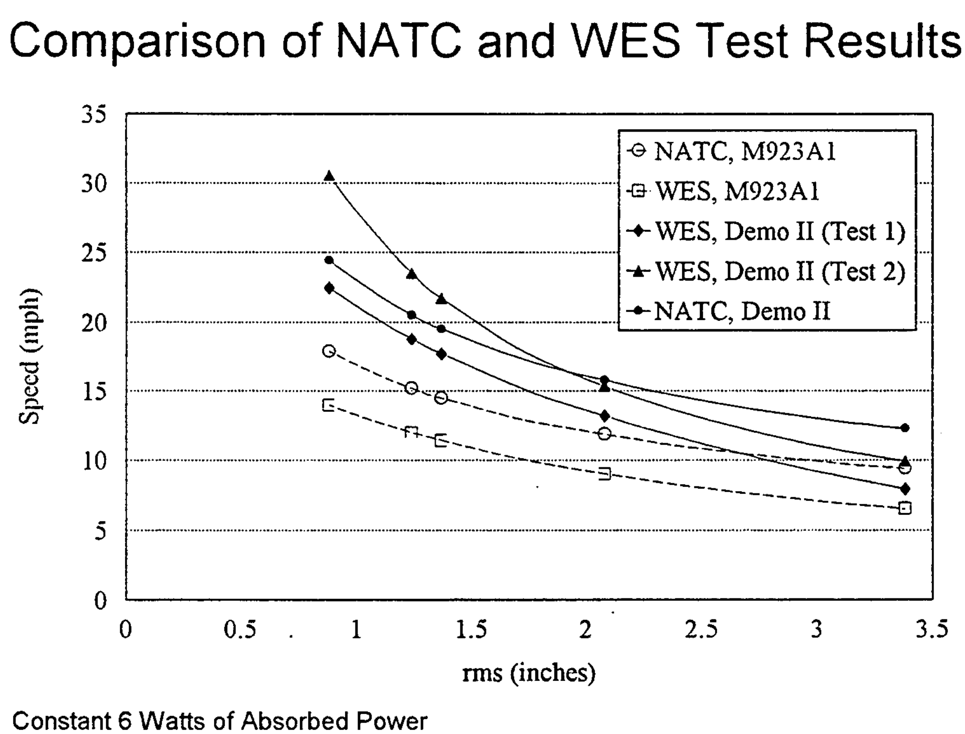

Figure 14

A compilation of various runs can be found in figure 14. WES data points in this figure were obtained from best fit equations generated from the actual test data interpolated to 6 watts of absorbed power. NATC data points were obtained from the best fit equations generated from testing performed there. Both M923A1 tests, at WES and NATC, are presented as the dashed lines. The M923A1 ran better at NATC than at WES. Since the margin of difference between both M923A1 vehicles is fairly constant, the terrain becomes the most likely cause of this difference. In accordance with the better performance of the M923A1 at NATC, the Demo II at NATC should also have the same margin of better performance when compared to its runs at WES. But the Demo II run at NATC does not have the same margin of better performance over its run at WES, represented by test 1. The additional performance difference at NATC is primarily due to the extra 2000 pounds of payload. This extra payload appears to hurt the vehicle on smoother terrain while helping it over rougher terrain.

While there are differences in the performance of the respective vehicles at NATC, the important results are still clearly visible. When comparing only NATC test results, the Demo II, with the fully independent suspension, outperformed the M923A1, with the solid axle suspension, by a respectable margin. This, in turn, verifies data obtained at WES that indicates the same conclusions.

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APPENDICES

APPENDIX A

Comparison of WES Test Vehicles

	M923A1, Baseline	Demo II, Configuration 1	Demo II, Configuration 2
Test Weight (lbs)	32530	32830	33190
Tires	Michelin 1400R20XL radial	Michelin 1400R20XML radial	Michelin 1400R20XML radial
Tire Inflation Pressure (psi)	35	35	32 front / 26 rear
Tire Contact Area (in^2)	203	210	210
Tread Depth (in)	.75	.75	.75
Front Spring Rate (lbs/in)	2271	750*	1250*
Rear Spring Rate (lbs/in)	5983 (tandem)	1250*	1250*

* At each wheel position

APPENDIX B

Ride Dynamics Test Results
Demo II

Test No.	Direction of Travel Station	Speed mph	Absorbed Power watts
Technology Demonstrator (Test 1), Ride Dynamics Course 1, 0.88 rms			
19	0-5	4.88	0.22
20	5-0	5.74	0.24
21	0-5	11.55	0.57
22	5-0	11.82	0.63
23	0-5	20.90	1.88
24	5-0	19.23	1.54
25	0-5	12.56	0.76
26	5-0	14.07	0.84
27	0-5	25.68	3.30
28	5-0	25.57	2.72
29	0-5	32.06	3.93
30	5-0	31.04	3.91
31	0-5	33.58	3.49
32	5-0	34.50	3.71
33	0-5	37.58	4.25
34	5-0	35.54	4.08
35	0-5	37.50	4.55
36	5-0	27.89	3.76
Technology Demonstrator (Test 1), Ride Dynamics Course 5, 1.24 rms			
38	5-0	4.23	0.25
39	0-5	8.25	0.40

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40	5-0	9.70	0.61
41	0-5	12.85	1.38
42	5-0	14.98	2.07
43	0-5	18.40	3.33
44	5-0	17.37	2.87
45	0-5	24.86	7.25
46	5-0	24.00	5.04
47	0-5	20.29	4.35
48	5-0	21.56	4.19
49	0-5	22.57	5.51
50	5-0	23.73	5.14
51	0-5	26.38	8.25
52	5-0	26.65	7.12
53	0-5	30.54	10.88
56	5-0	30.06	14.12
58	0-5	31.56	11.15
59	5-0	31.10	16.79

Technology Demonstrator (Test 1), Ride Dynamics Course 4, 1.37 rms

60	0-5	4.69	0.30
61	5-0	5.32	0.29
62	0-5	12.13	2.62
63	5-0	9.23	1.12
64	0-5	15.43	4.08
65	5-0	13.97	3.47
66	0-5	19.38	7.47
67	5-0	17.76	6.05
68	0-5	22.62	9.68
69	5-0	22.53	10.96
70	0-5	24.41	13.79
71	5-0	25.06	10.80

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Technology Demonstrator (Test 1), Ride Dynamics Course 6, 2.08 rms

72	0-5	5.12	0.29
73	5-0	4.89	0.28
74	0-5	7.82	0.68
75	5-0	8.21	0.84
76	0-5	10.30	2.08
77	5-0	10.23	1.92
78	0-5	11.68	4.17
79	5-0	12.46	4.11
80	0-5	14.56	7.34
81	5-0	14.49	10.41
82	0-5	15.98	17.54
83	5-0	15.50	11.26

Technology Demonstrator (Test 1), Ride Dynamics Course 7, 3.38 rms

84	0-5	5.61	1.16
85	5-0	5.58	1.02
86	0-5	8.98	9.40
87	5-0	8.58	6.54
88	0-5	9.75	12.16
89	5-0	9.58	12.86
90	0-5	8.60	6.80
91	5-0	7.74	3.06

Technology Demonstrator (Test 2), Ride Dynamics Course 1, 0.81 rms

1	0-5	9.39	0.37
2	5-0	9.86	0.40
3	0-5	19.36	1.46

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4	5-0	19.58	1.37
5	0-5	19.07	1.39
6	5-0	24.31	2.17
7	0-5	28.38	3.55
8	5-0	29.06	3.24
9	0-5	32.49	3.67
10	5-0	32.43	3.54
11	0-5	36.77	4.25
12	5-0	33.52	3.66

Technology Demonstrator (Test 2), Ride Dynamics Course 4, 1.28 rms

30	5-0	10.48	0.88
31	0-5	15.57	3.33
32	5-0	15.26	3.42
33	0-5	19.05	5.46
34	5-0	19.36	6.07
35	0-5	21.65	5.60
36	5-0	22.10	6.70
37	0-5	23.23	6.10
38	5-0	23.77	7.35
39	0-5	25.98	7.77
40	5-0	25.96	8.78
41	0-5	28.19	9.85
42	5-0	28.98	9.75
43	0-5	29.74	10.23

Technology Demonstrator (Test 2), Ride Dynamics Course 5, 1.16 rms

13	0-5	9.60	0.50
14	5-0	10.26	0.56

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15	0-5	14.72	1.98
16	5-0	15.01	1.99
17	0-5	18.84	3.68
18	5-0	19.19	3.76
19	0-5	21.88	4.93
20	5-0	21.86	4.45
21	0-5	24.05	6.48
22	5-0	24.50	5.31
23	0-5	25.45	6.84
24	5-0	26.59	6.33
25	0-5	29.06	9.27
26	5-0	28.22	8.01
27	0-5	30.24	8.72
28	5-0	30.19	10.62

Technology Demonstrator (Test 2), Ride Dynamics Course 6, 2.03 rms

45	0-5	5.86	0.32
46	5-0	6.01	0.32
47	0-5	7.62	0.46
48	5-0	7.89	0.48
49	0-5	9.77	1.06
50	5-0	9.97	1.19
51	0-5	13.16	4.48
52	5-0	13.14	4.01
53	0-5	15.37	6.39
54	5-0	15.31	5.90
55	0-5	16.60	9.32
56	5-0	16.87	9.65

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Technology Demonstrator (Test 2), Ride Dynamics Course 7, 3.38 rms

57	0-5	5.36	0.48
58	5-0	5.62	0.61
59	0-5	7.64	1.41
60	5-0	7.45	1.28
61	0-5	9.60	5.07
62	5-0	9.74	5.65
64	5-0	10.36	6.67
65	0-5	10.35	6.57
66	5-0	10.60	14.46
67	0-5	10.44	8.99
68	0-5	10.15	9.27

APPENDIX C

Ride Dynamics Test Results
M923A1

Test No.	Direction of Travel Station	Speed mph	Absorbed Power watts
M923A1 (Test 1), Ride Dynamics Course 1, 0.88 rms			
1	0-5	6.34	0.33
2	5-0	5.91	0.37
3	0-5	11.48	2.42
4	5-0	11.10	2.75
5	0-5	17.41	16.14
6	5-0	17.41	16.50
7	0-5	14.67	5.87
8	5-0	14.67	8.05
9	0-5	16.27	17.73
10	5-0	16.44	18.22
M923A1 (Test 1), Ride Dynamics Course 5, 1.24 rms			
37	0-5	5.41	0.26
38	5-0	5.47	0.29
39	0-5	9.90	1.95
40	5-0	9.71	1.70
41	0-5	14.14	15.42
43	5-0	11.45	3.41
44	0-5	11.69	3.77
45	5-0	13.38	8.31
46	0-5	14.09	12.95

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M923A1 (Test 1), Ride Dynamics Course 4, 1.37 rms

47	0-5	5.71	0.44
48	5-0	5.83	0.52
49	0-5	9.63	3.94
50	5-0	9.61	4.60
53	0-5	10.59	6.72
54	5-0	11.38	9.22

M923A1 (Test 1), Ride Dynamics Course 6, 2.08 rms

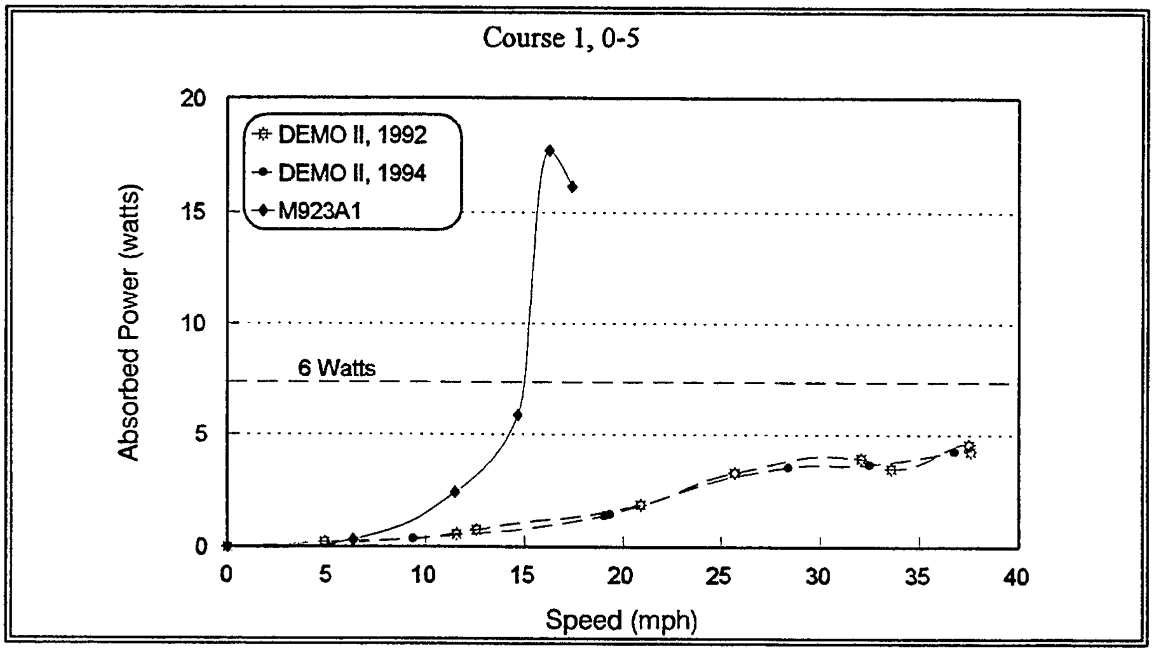
55	0-5	6.05	0.49
56	5-0	5.50	0.41
57	0-5	8.13	2.38
58	5-0	8.33	2.62
59	0-5	10.60	6.78
60	5-0	10.35	6.71
63	0-5	10.88	10.05
64	5-0	10.66	6.88

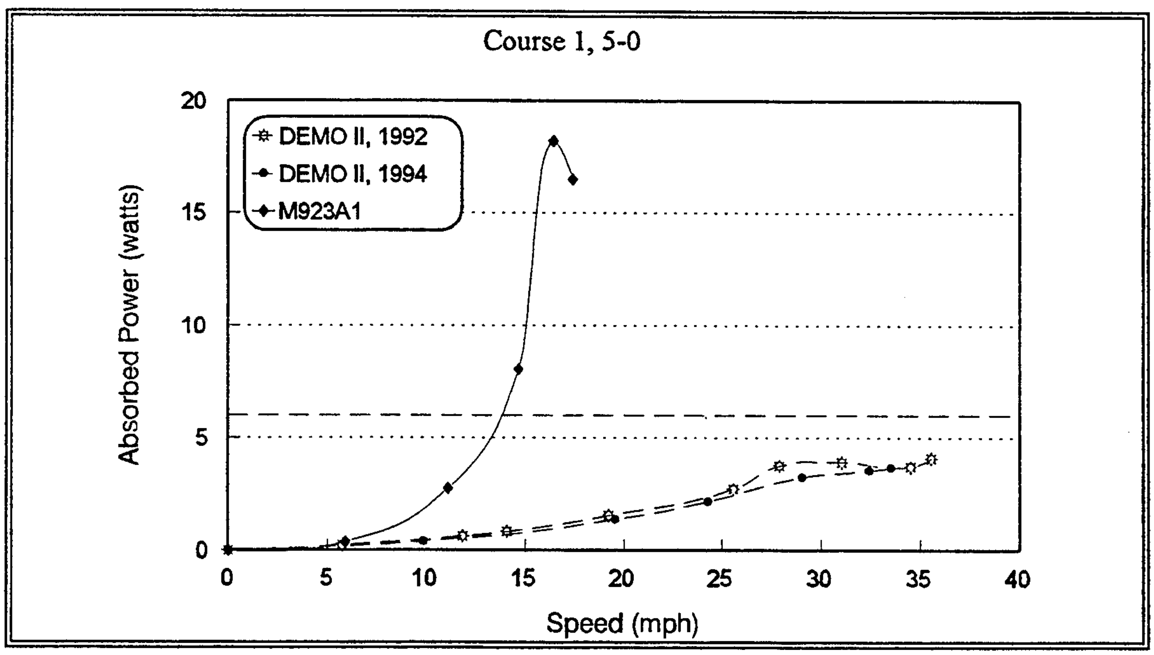
M923A1 (Test 1), Ride Dynamics Course 7, 3.38 rms

65	0-5	5.84	2.32
66	5-0	5.80	1.41
67	0-5	4.09	0.37
68	5-0	3.96	0.36
69	0-5	6.97	11.48
70	5-0	7.15	10.63

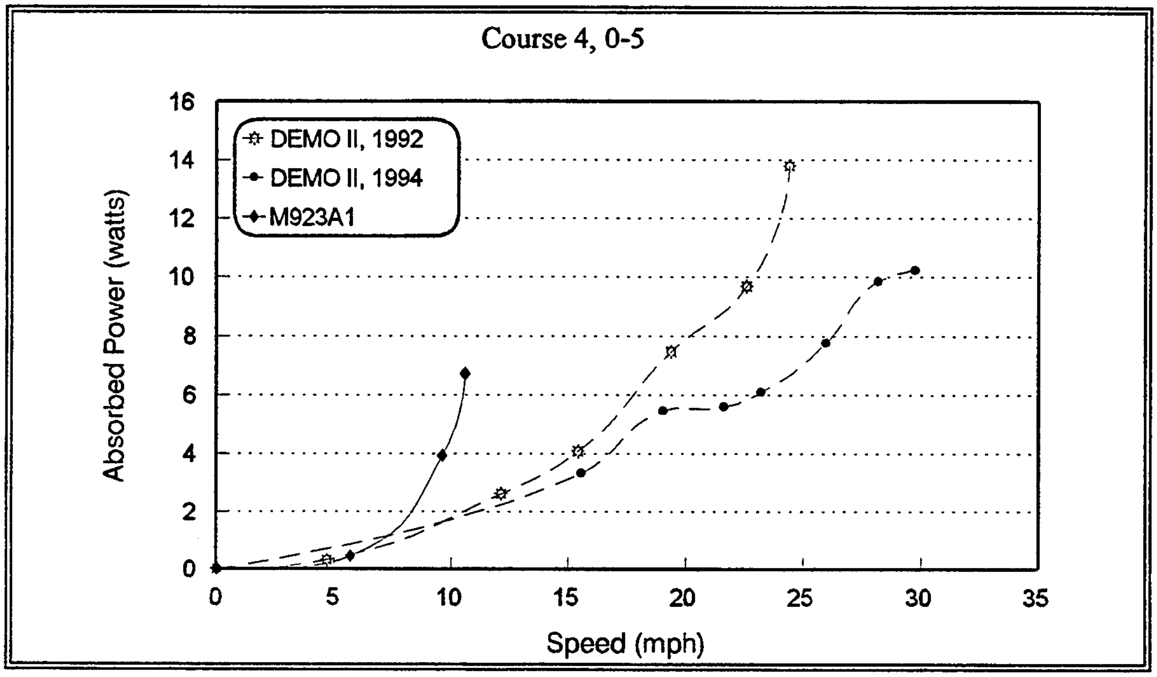
APPENDIX D

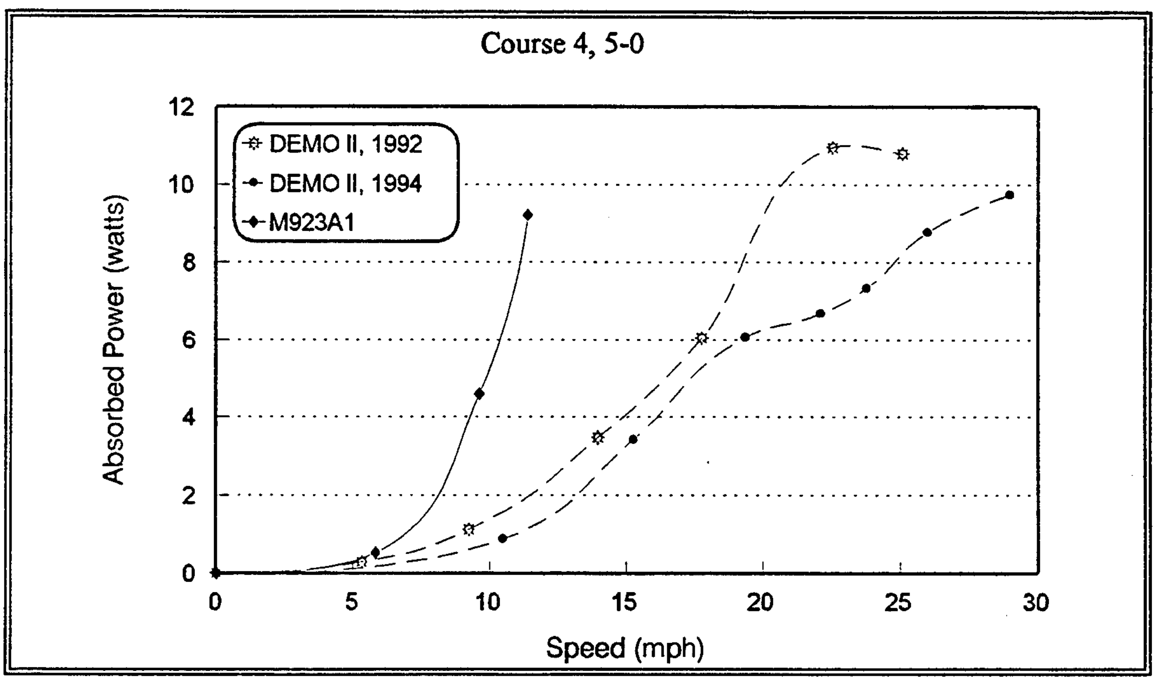
Graphs of Absorbed Power Versus Vehicle Speed Generated from Ride Dynamics Testing at WES



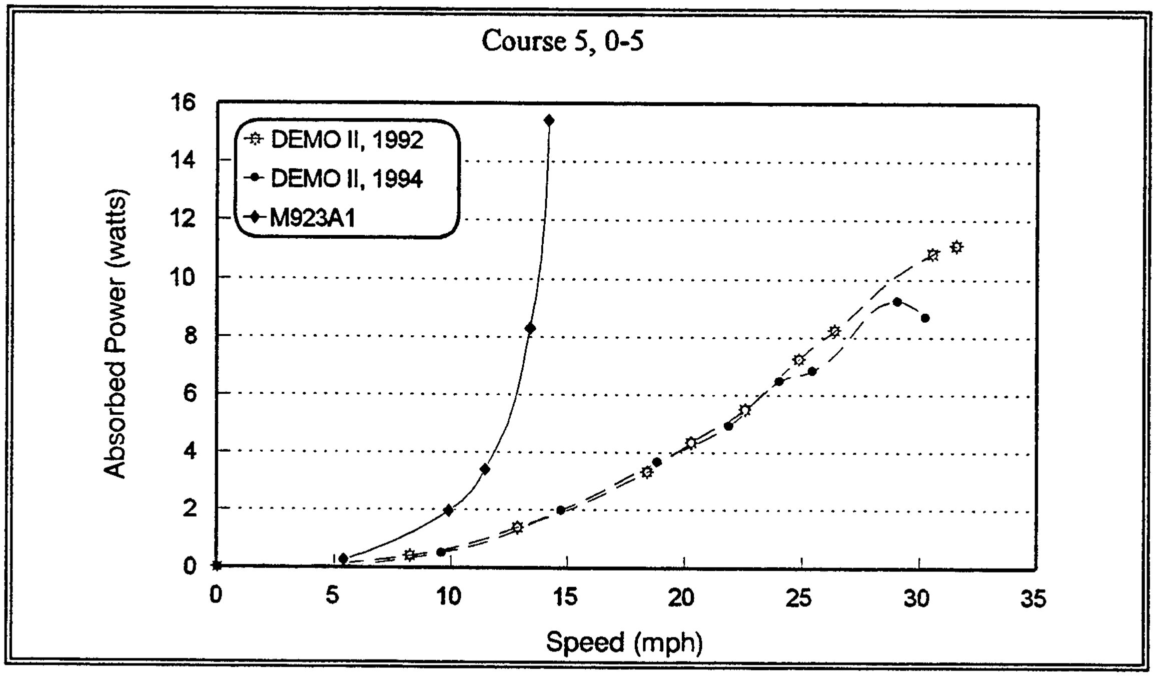


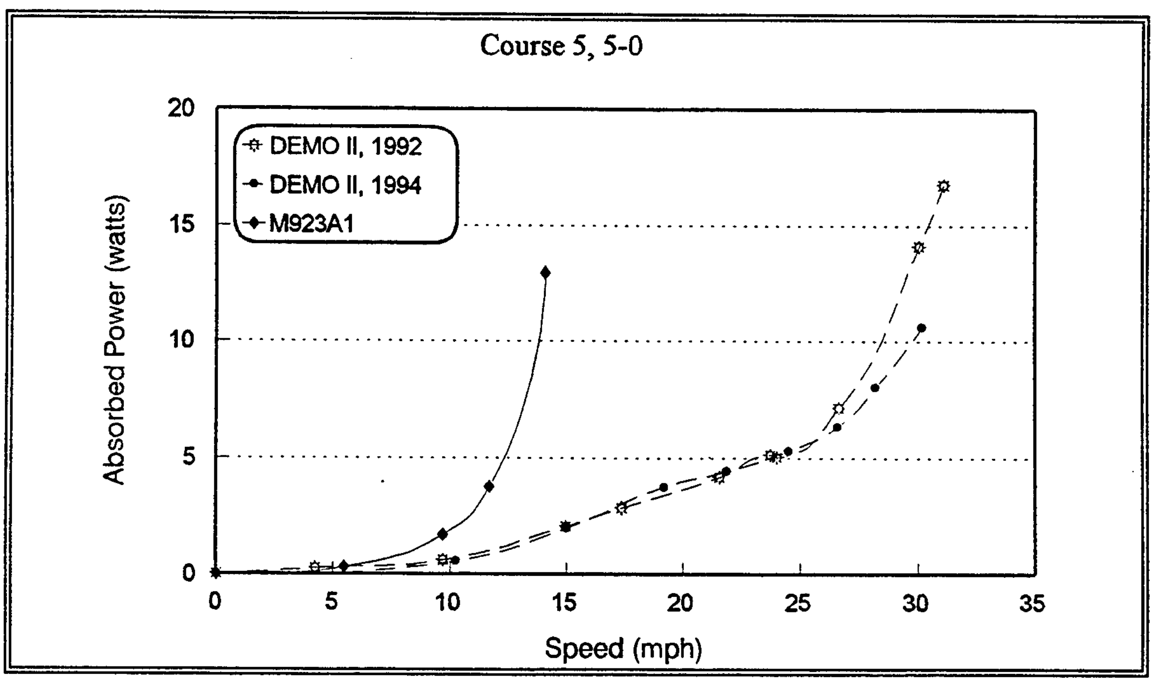
APPENDIX D


Course 4, 0-5
DEMO II, 1992
DEMO II, 1994
M923A1
Absorbed Power (watts)
Speed (mph)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
35

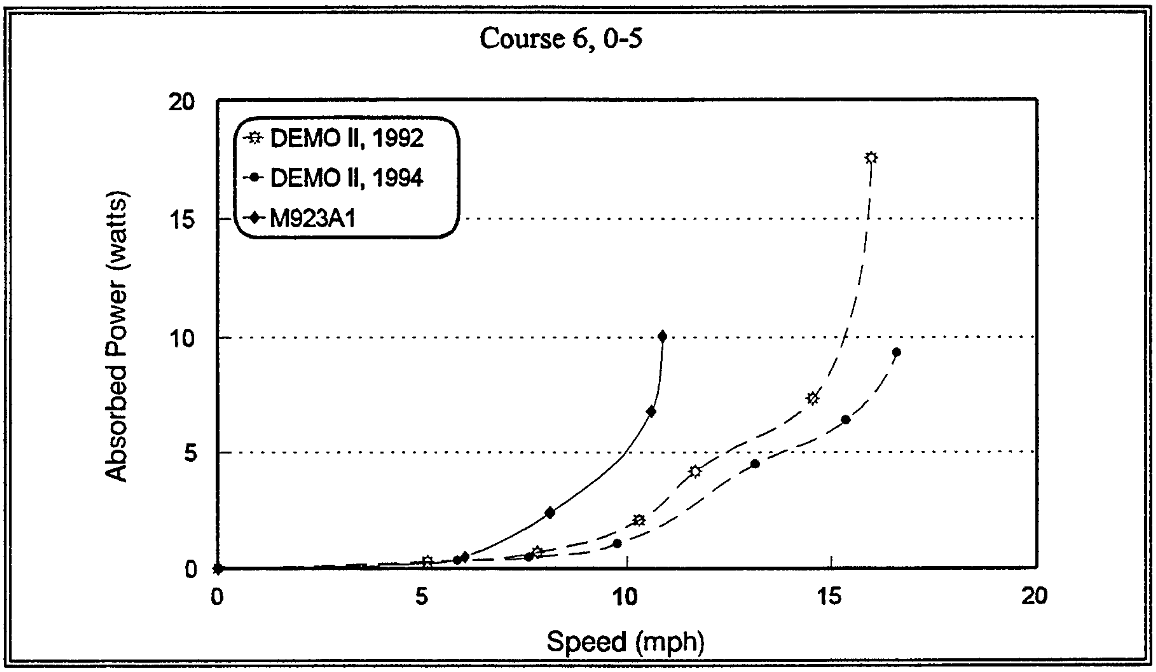

Course 4, 5-0
DEMO II, 1992
DEMO II, 1994
M923A1
Absorbed Power (watts)
Speed (mph)
0
2
4
6
8
10
12
0
5
10
15
20
25
30

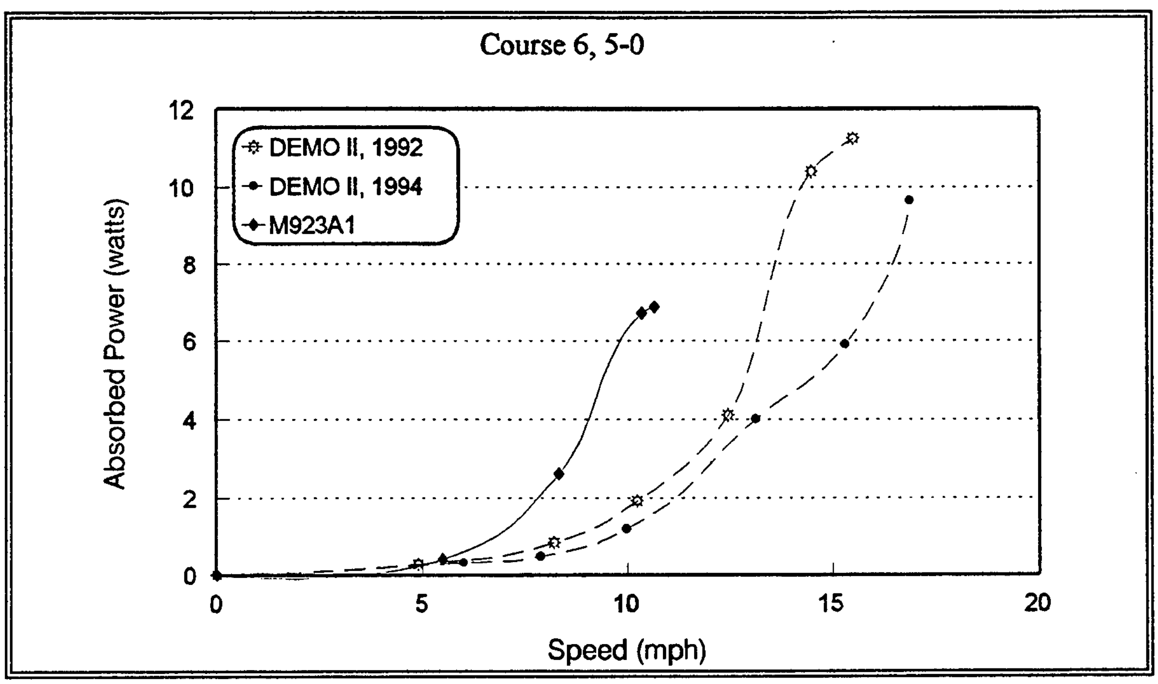
APPENDIX D


Course 5, 0-5
Absorbed Power (watts)
16
14
12
10
8
6
4
2
0
DEMO II, 1992
DEMO II, 1994
M923A1
0
5
10
15
20
25
30
35
Speed (mph)

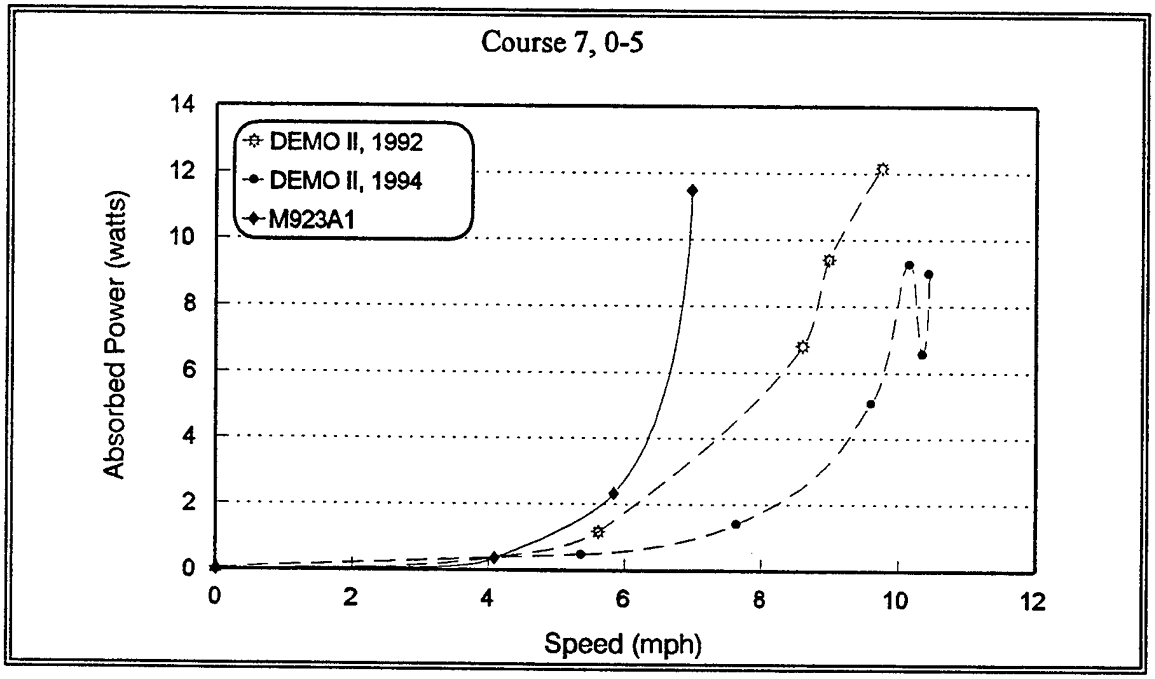

Course 5, 5-0
Absorbed Power (watts)
20
15
10
5
0
DEMO II, 1992
DEMO II, 1994
M923A1
0
5
10
15
20
25
30
35
Speed (mph)

APPENDIX D

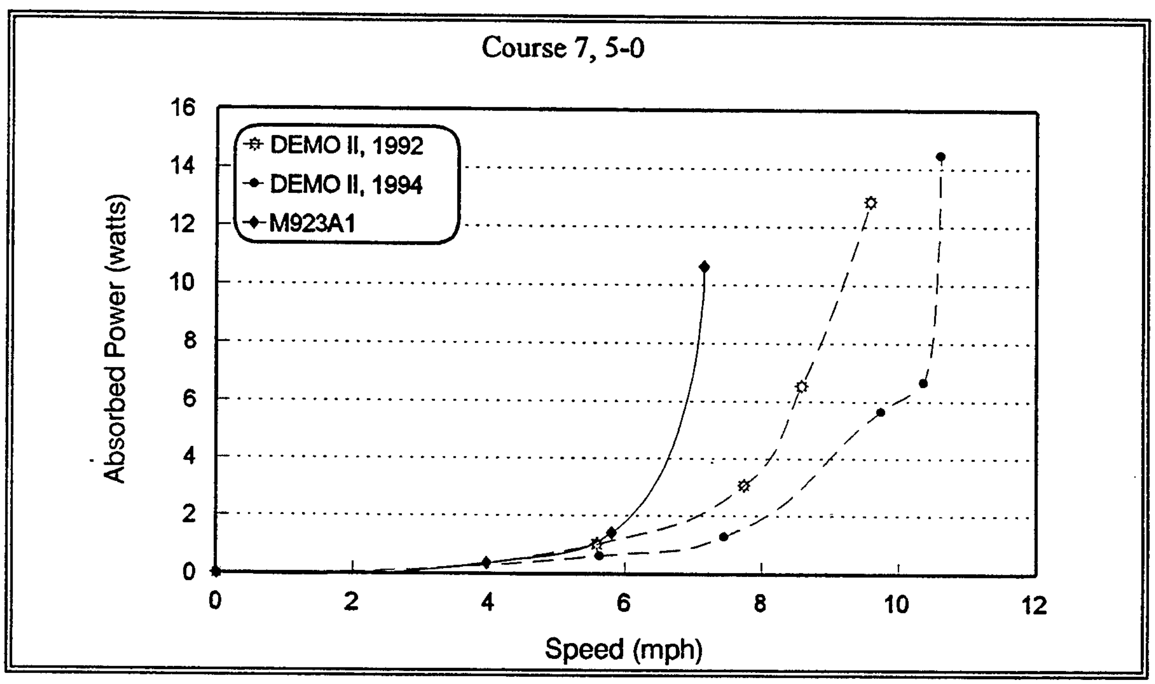

Course 6, 0-5
DEMO II, 1992
DEMO II, 1994
M923A1
Absorbed Power (watts)
0
5
10
15
20
Speed (mph)


Course 6, 5-0
DEMO II, 1992
DEMO II, 1994
M923A1
Absorbed Power (watts)
0
2
4
6
8
10
12
0
5
10
15
20
Speed (mph)

APPENDIX D



Course 7, 0-5
DEMO II, 1992
DEMO II, 1994
M923A1
Absorbed Power (watts)
Speed (mph)
0
2
4
6
8
10
12
14



Course 7, 5-0
DEMO II, 1992
DEMO II, 1994
M923A1
Absorbed Power (watts)
Speed (mph)
0
2
4
6
8
10
12
14
16

APPENDIX E

Shock Test Results
Demo II

Test No.	Obstacle Height, in.	Maximum Peak Acceleration Under Drivers Seat, g's	Speed mph
Technology Demonstrator (Test 1, 1992)			
92	6	0.8	4.89
93	6	0.95	9.81
94	6	0.79	14.21
95	6	1.29	19.17
96	6	1.46	24.39
97	6	2.23	29.51
98	6	1.62	32.54
99	6	1.08	34.87
100	6	2.31	26.37
101	6	2.36	27.1
102	6	2.3	28.7
103	8	1.02	4.62
104	8	1.16	9.79
105	8	1.47	14.59
106	8	2.05	18.42
108	8	2.81	25.2
110	8	1.96	23.22
111	8	2.25	25.2
112	8	3.5	27.82
113	8	3.03	27.1

APPENDIX E

114	10	1.89	5.29
115	10	2.78	9.48
116	10	2.46	8.2
117	10	1.83	5.99
118	10	1.08	3.34
119	12	1.16	3.35
120	12	1.39	3.9
122	12	2.18	6.19
123	12	2.65	6.79
124	12	1.49	4.14

Technology Demonstrator (Test 2, 1994)

69	6	1.04	10.19
70	6	0.82	14.23
71	6	1.47	20.23
72	6	1.41	24.13
73	6	1.65	28.29
74	6	1.49	33.01
75	6	1.32	39.63
76	8	0.98	5.88
77	8	1.37	10.11
79	8	1.59	14.88
80	8	1.62	19.09
81	8	2.28	23.55
82	8	3.26	26.02
83	8	2.7	26.07
84	8	2.49	24.79

APPENDIX E

86	10	1.09	6.34
87	10	1.87	8.06
88	10	2.33	10.21
90	10	2.49	12.15
91	10	2.1	15
92	10	2.35	13.78
93	10	2.52	13.21
94	10	2.32	17.39
95	10	2.55	18.35
96	10	2.45	12.69
97	12	0.59	3.37
98	12	2.1	6.16
99	12	1.77	6.58
101	12	2.2	7.78
103	12	2.79	10.7
104	12	2.68	9.61
105	12	2.47	8.83
107	12	1.63	4.81

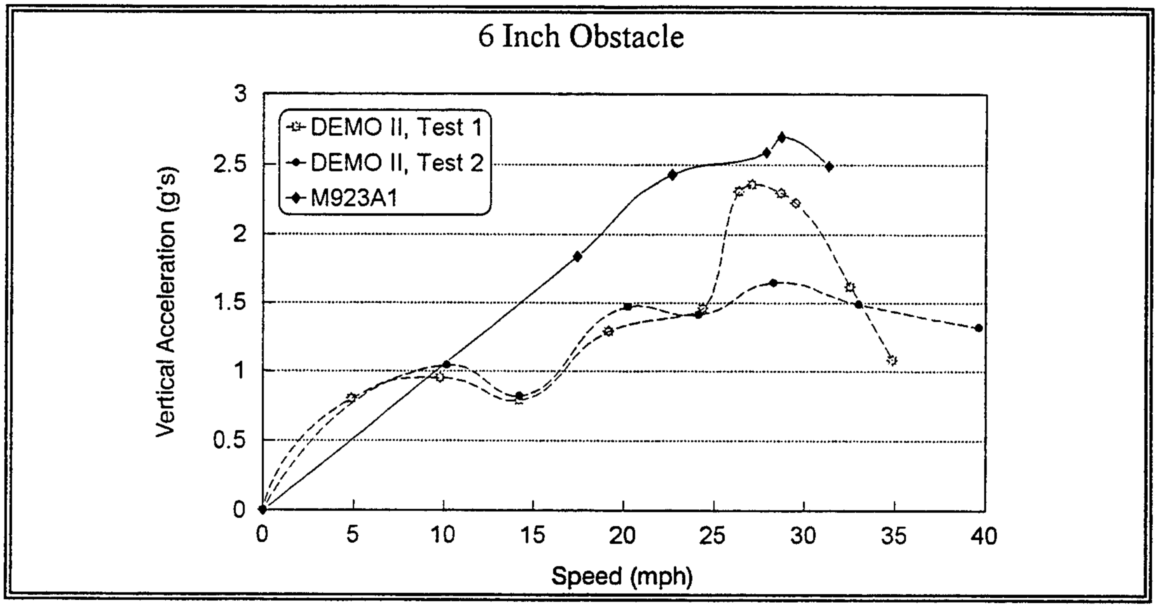
APPENDIX F

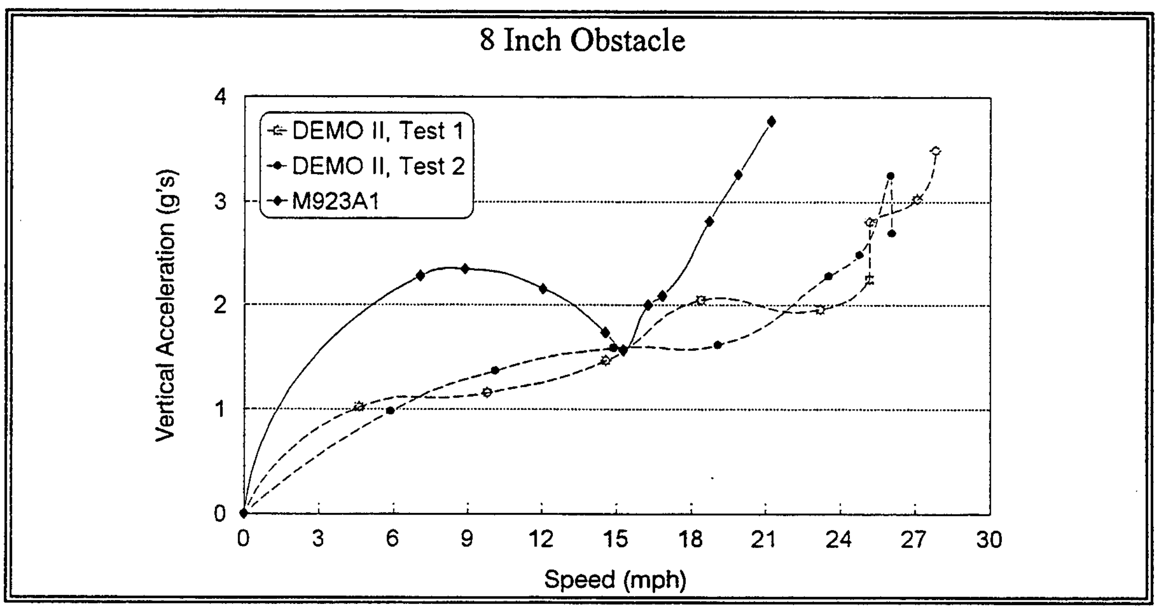
Shock Test Results
M923A1

Test No.	Obstacle Height, in.	Maximum Peak Acceleration Under Drivers Seat, g's	Speed mph
		M923A1 (Test 1, 1992)	
125	6	2.43	22.65
126	6	2.59	27.88
127	6	2.49	31.34
128	6	2.7	28.7
129	6	1.84	17.43
130	8	2.16	12.06
131	8	2.35	8.89
132	8	2.28	7.09
133	8	1.74	14.56
134	8	2	16.29
135	8	1.57	15.28
136	8	3.78	21.23
138	8	2.09	16.85
139	8	3.27	19.9
140	8	2.82	18.75
141	10	2.99	4.27
142	10	1.03	3.08
143	10	1.46	3.93

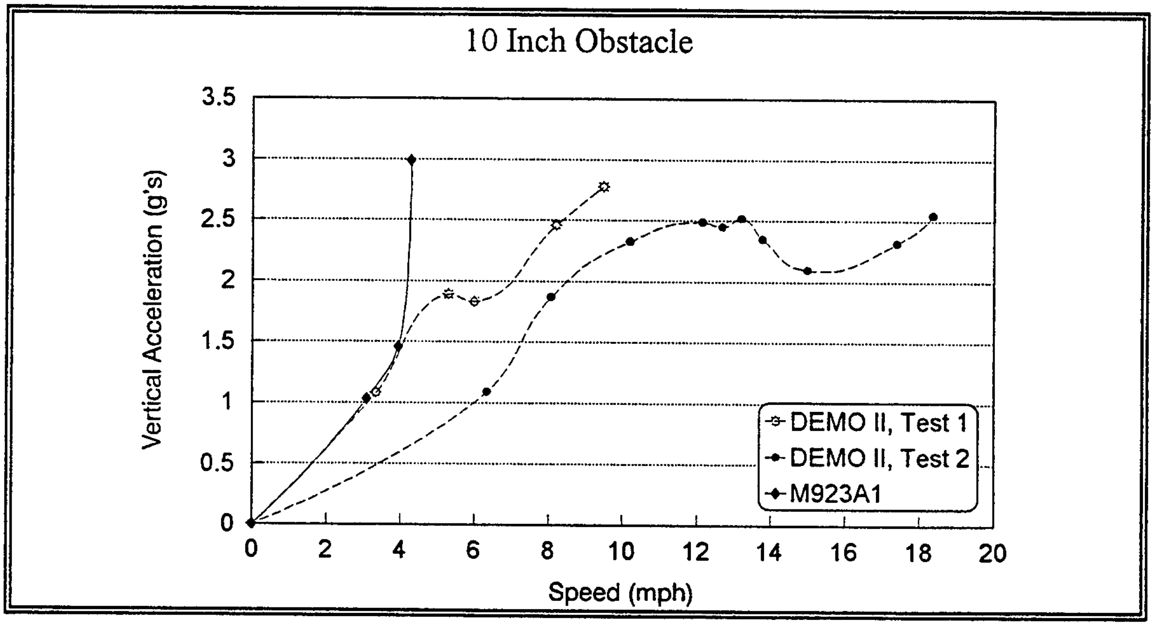
APPENDIX G

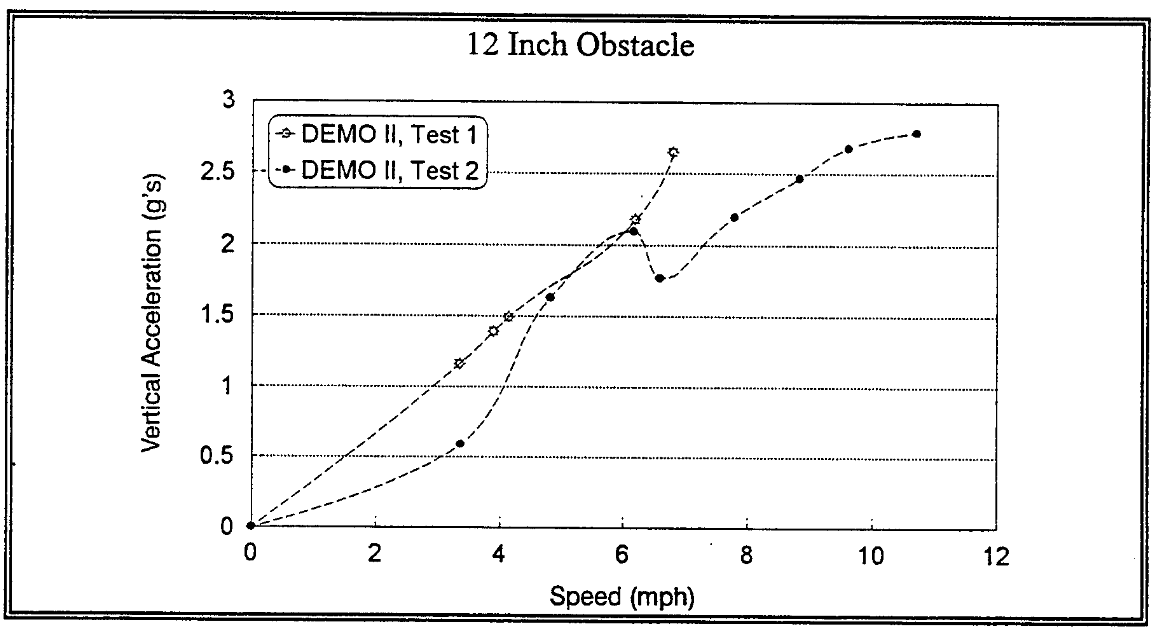
Shock Test Results: Vertical Acceleration vs. Vehicle Speed





APPENDIX G


10 Inch Obstacle
3.5
3
2.5
2
1.5
1
0.5
0
Vertical Acceleration (g's)
0
2
4
6
8
10
12
14
16
18
20
Speed (mph)
DEMO II, Test 1
DEMO II, Test 2
M923A1


12 Inch Obstacle
3
2.5
2
1.5
1
0.5
0
Vertical Acceleration (g's)
0
2
4
6
8
10
12
Speed (mph)
DEMO II, Test 1
DEMO II, Test 2

APPENDIX H

Ride Dynamics Test Results
NATC