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MOBILITY IN NATURAL ENVIRONMENTS

REPORT I

VEGETATION OVERRIDE TEST METHODS

FINAL REPORT

BY

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SEPTEMBER 1974

UNITED STATES ARMY TROPIC TEST CENTER

APO NEW YORK 09827

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

The United States Army Tropic Test Center conducted a vehicular/vegetation mobility investigation during the rainy season of 1974 in the humid tropic environment of the Canal Zone. Objectives were to (a) evaluate subtests currently being conducted or that could be devised to evaluate the interaction of vehicles with tropic vegetation, and suggest appropriate subtests for use in conduct of tropic vehicular studies; (b) compile performance data from tests with a few selected vehicles in the Canal Zone for use as guidelines in future tropic mobility studies; (c) provide test data for use by US Army Tank-Automotive Command in further verification and refinement of the AMC '71 Mobility Model; and (d) obtain test results that could be used as guidelines for the modification of MTPs 2-3-504 and 2-4-003: "Cross-Country Mobility" and "Wheeled, Tracked, and General Purpose Vehicles."

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Results of tests indicated : (a) the force required to fail or override single and multiple trees in the tropics can be predicted from the stem diameter measured at breast height (DBH), (b) the capability of vehicles to traverse tropic forested areas is highly dependent on the driver's visibility through such areas, (c) tropic grasslands affect maneuverability and penetration capabilities of standard military vehicles by increasing the time and forces required to travel through such areas, and (d) a single generalized equation can be used that accurately relates tree stem diameter to the force required to fail/override tropic trees using standard military wheeled vehicles.

Formulae are given for the following conditions: (a) force to fail a tree with an M151A1, ¼-ton truck; (b) force to fail a tree with an M715, 5/4-ton truck; (c) force to fail a tree with an M36A2, 5/2-ton truck; (d) generalized equation for force required to fail a tree with wheeled vehicles; (e) force to fail/override a tree with an M151A1, ¼-ton truck; (f) force to fail/override a tree with an M715, 5/4-ton truck; (g) force to fail/override a tree with an M36A2, 5/2-ton truck; (h) generalized equation for force to fail/override a tree with wheeled vehicles; and (i) relative force required to fail/override multiple trees as opposed to single trees.

FOREWORD

During FY72 the United States Army Tropic Test Center (USATTC) conducted a methodology investigation to evaluate subtests currently being conducted or that could be devised to evaluate the interaction of vehicles with terrain, and to suggest appropriate subtests for use in tropic vehicular testing. Although several tests were found acceptable, techniques for quantifying the interaction of vehicles with vegetation were found to be lacking. This led USATTC to develop a formal requirement for research to investigate techniques for evaluating vehicle/vegetation interactions. The Commander, United States Army Test and Evaluation Command, approved the research proposal in June 1973 and provided funds for its accomplishment. Testing was conducted during the rainy season of 1974.

USATTC is indebted to Howard Dugoff, United States Army Tank-Automotive Command, and A. A. Rula, United States Army Waterways Experiment Station for providing background information used to ensure that results obtained in this investigation would be compatible with and contribute towards improving the predictive capabilities of the AMC '71 Mobility Model.

Special acknowledgement is also given the following, who contributed significantly to successful completion of this research: 193d Infantry Brigade (Canal Zone); and USATTC staff members, MAJ C. A. Novack, who provided qualified drivers; CW2 J. W. Williams, who coordinated the maintenance and repair efforts of vehicles; and Dr. J. H. Kitchen, who provided soils analysis support. This research was conducted under the supervision of Dr. D. A. Dobbins, Chief, Analysis Division, USATTC.

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INTRODUCTION

Background

There are many facets of the environment that influence the capability of a vehicle to move cross-country. These include such factors as soil strength, slope characteristics, vegetation characteristics, and hydrologic features. For a number of years research sponsored by the Army Materiel Command (AMC) and other DOD organizations has been conducted in the mobility field in an effort to quantify the relations between vehicular mobility characteristics and the environment. Much of the research emphasis has been placed on the conduct of vehicular performance studies in the natural environment. Considerable efforts, however, have also been expended on development of mathematical models for predicting vehicle performance characteristics and on development of techniques for classifying terrain features in such a manner that they are meaningful in terms of predicting trafficability conditions.

One of the earlier vehicular performance studies in the tropics was conducted in the Republic of Panama by the US Army Transportation Board during the early 1960s. These studies conducted under the Swamp Fox I[1] and Swamp Fox II[2] projects were designed to permit development of accurate scientific and engineering data on the relationship between equipment and the environment. Results showed tracked vehicles to be superior to wheeled vehicles for use in tropical terrain. Marginal performance was obtained from wheeled vehicles equipped with standard military and commercial tires; but, in general, only the aggressive tread, wide-base tires provided such vehicles even marginal off-road mobility.

In addition to the Swamp Fox studies conducted in Panama, many other government agencies have performed mobility research in tropical regions of the world. In the 1960s, potential trouble spots in Southeast Asia, equatorial Africa, and the Caribbean area highlighted the necessity of seeking improvements in the US Army's capability to operate effectively in tropic environments. Numerous tests[3-7] were conducted by the US Military Research and Development Center in Thailand. Basically these tests were comparisons of one or more vehicles to determine the most suitable for use in tropic combat areas such as Vietnam. Tests of the M715, 5/4-ton truck[7] are typical of those conducted. Objectives were to determine the capability of the M715, equipped with standard 9 x 16 tires, to operate cross-country on jungle and mountain trails, and also if the cross-country mobility of the M715 could be improved by using oversize tires (11 x 18 and 15 x 19.5) or tire chains. The M37B truck (cargo, 3/4-ton, 4 x 4) equipped

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1 *Swamp Fox I*, 1962.
2 *Swamp Fox II*, 1964.
3 MRDC *Semiannual Report 15 May–15 Nov 65.*
4 *Mobility Tests of the XM-571 in Thailand.*
5 *Comparative Tests of the XM-561, XM-571, SPRYTE, M-116, and M-37 in Thailand.*
6 *"MUDLARK": Tests of the FV 432 STALWART, M113-1/2, M551 and FV 347 in Thailand.*
7 *Tests in Thailand of Truck, Cargo, 1¼-Ton, 4X4, M715.*

with standard 9 x 16 tires was used as the comparison vehicle. Results indicated that the M715 with standard tires was unsatisfactory for off-the-road operations when encountering soft soils and jungle and mountain trails. Data indicated a significant improvement in cross-country mobility when the M715 was equipped with oversize tires. The cross-country mobility of the M37B with standard tires was better than that of the M715 with standard tires. The M715 equipped with standard tires performed well on highways and improved hard-surface roads. Oversize tires were recommended for use for cross-country operations, including driving over jungle and mountain trails in Thailand.

The US Army Waterways Experiment Station (USAWES), which conducted numerous tests[8-12] in the tropics and other regions of the world, has contributed to quantification of the effects of the environment on vehicular mobility and to development of mathematical models for predicting vehicle performance characteristics. Typical of tests conducted by USAWES are a study[8] of the effects of jungle trail characteristics on vehicle performance and a study[9] of soil-vehicle relations on soft clay soils. In the jungle trail tests conducted in Thailand vehicles with widths approaching 90 inches had difficulty along jungle trails. Overhanging vegetation and fallen trees restricted driver visibility and damaged windshields on vehicles with heights of 80 inches or more. Slippery soils and steep streambanks plagued trail operations; deep ruts in the trail surface also caused considerable problems. Nonamphibious vehicles had numerous engine failures in fording operations. In the soil-vehicle relations study, 66 acceleration-deceleration tests were conducted with three wheeled and two tracked vehicles at five separate sites in Thailand. The principal conclusion was that vehicle deceleration in soft clay soils can be correlated with soil strength expressed as the average 0- to 6-inch cone index. Analysis indicated that acceleration increased with an increase in soil strength, but no definitive correlation could be established. Semiempirical and empirical relations were used in a first-generation analytical model to predict average speed over the test courses. Comparisons of measured and predicted speeds led to recommendations for specific additional studies to improve the reliability of the USAWES analytical model.

The US Army Tropic Test Center (USATTC) has conducted mobility evaluations of military vehicles in the tropics for a number of years. Vehicles tested have included the LVTPX12 assault amphibian personnel carrier[13] and the XM561 5/4-ton truck.[14] Evaluation of the LVTPX12 included jungle mobility tests conducted in open marsh areas, mangrove swamps, lowland jungle, upland jungle, elephant grass and river banks. Basically, the LVTPX12 was operated as far as it would go. In some instances this amounted to 50 miles; in others, a few hundred meters. The LVTPX12 was found to be capable of performing well in open marsh and lowland jungle, but it was often immobilized in other

[8] *Utility Carrier Development Program, Rep. I, Limited Study of Effects of Jungle Trail Characteristics on Performance of Selected Self-Propelled Vehicles.*

[9] *An Analytical Model for Predicting Cross-Country Vehicle Performance, App. F. Soil-Vehicle Relations on Soft Clay Soils (Surface Composition).*

[10] *An Analytical Model for Predicting Cross-Country Vehicle Performance, App. B. Vehicle Performance in Lateral and Longitudinal Obstacles (Vegetation), Vol. II: Longitudinal Obstacles.*

[11] *One-Pass Performance of Vehicles on Fine-Grained Soils.*

[12] *An Analytical Model for Predicting Cross-Country Vehicle Performance, App. D. Performance of Amphibious Vehicles in the Water-Land Interface (Hydrologic Geometry).*

[13] *Assault Amphibian Personnel Carrier, Experimental (LVTPX12).*

[14] *Integrated Engineering/Service (Tropic Environmental) Test of Truck, Cargo, 1¼-Ton, 6x6, XM561.*

areas. After 15 miles in the jungle grassland area, excessive grass buildup in the suspension system caused the track to be thrown repeatedly from the sprocket. The vehicle's fragile bow pod and lighter weight prevented it from smashing through the dense mangrove trees. Exits from rivers with steep muddy banks presented problems when carrying a 10,000-pound combat load; however, in the combat equipped condition the vehicle successfully negotiated 80 percent of the same exit points. In most test areas the LVTPX12 exhibited mobility characteristics superior to the two accompanying M113 Armored Personnel Carriers.

Emphasis during the XM561 tests was placed on endurance, reliability, and mobility operations. A total of 1500 miles was accumulated on the truck while carrying a rated payload. The test vehicle exhibited superior overall performance over other comparable tactical wheeled vehicles. The most important areas requiring improvement included brake endurance and ease of steering.

Prior to 1967 at USATTC, this type of testing was for the most part through use of unimproved roads located throughout the Canal Zone and, in most cases, in areas in which a given terrain type was presumed to prevail. Terrain studies were conducted on a nonmethodical and usually subjective basis, consisting of a few soil strength measurements, qualitative vegetation descriptions, and generalized slope determinations. After 1967 at USATTC, tests were expanded to include off-road testing; however, quantification of the influence of the environment on vehicle mobility was not changed significantly. A need was established for objective quantification and systematizing of terrain factors and their effects on vehicular cross-country mobility. In May 1970, the Commander, US Army Test and Evaluation Command (TECOM), recognized the recurring need by the Army for systematic evaluation of the mobility of military vehicles in tropic environments and directed that USATTC take action to improve its vehicular test capabilities.

USATTC's initial efforts[15] in this direction were divided into two subtasks, mobility techniques and mobility test areas. The investigation categorized tropic terrain factors as soils, vegetation, topography, and hydrography; developed three new measurement procedures using simplified instrumentation; described procedures for field measurement of vegetation, stem-spacing density, grass density, soil textural classification, soil sampling, and soil mass strength; designated 11 off-road mobility areas, nine chosen for distinct vegetation types and two as representing Atlantic and Pacific coastal interfaces; designated one on-road course typifying terrain variation in the Canal Zone; mapped locations, distribution of predominant slopes, and topography of each of the 12 mobility areas.

In 1971 USATTC conducted a methodology investigation[16] to establish or adapt standard test procedures for use in the tropics for evaluating the suitability of newly developed vehicles. The result of this investigation was the selection of a number of test procedures: (a) one-pass VCI, (b) maximum drawbar pull, (c) acceleration-deceleration, (d) slope-negotiation, (e) maneuverability, (f) motion resistance–soil strength, and (g) natural obstacle tests for use in tropic mobility tests.

[15] *Canal Zone Mobility Test Areas and Terrain Measurements.*
[16] *Environmental Mapping of Tropic Test Sites, Rep. II, Vehicular Response Investigation.*

While the tests discussed in the above paragraphs provided techniques for evaluating the influence of most environmental factors previously mentioned, they were not designed to provide adequate techniques to determine influence of vegetation characteristics on the capability of vehicles to move cross-country. USAWES, US Army Transportation Board, and the Land Locomotion Laboratory of the US Army Tank-Automotive Center (TACOM) have conducted most of the research to quantitatively define vehicular/vegetation interactions. The open literature consists primarily of work done by the United States and its Allies, only one reference was found on work done in the U.S.S.R. This study briefly reports an empirical relation between felling moments of trees and stem diameter in tests conducted in the Tunguska meteorite area in Russia.[17] The results of the mobility/vegetation interaction test by USAWES[10] in the temperate United States and Asian tropics (Thailand) also support the conclusion that force and work to fail and override single and multiple trees may be predicted from the stem diameter.

Although much has been written about the impact of various environmental factors on the capability of a vehicle to move across terrain, integration of individual test results into a comprehensive model for the interaction of vehicles and terrain has proven a complex task. Recently there has emerged an analytical system which promises to provide the standard procedures so long needed for mobility evaluations. This system, called the AMC '71 Mobility Model,[18,19] is incomplete and inaccurate in some of its facets; but additional research such as the study reported herein under the sponsorship of AMC is expected to remedy these deficiencies. The AMC '71 Mobility Model is widely recognized in the mobility field as the best presently available tool for evaluating mobility and has been successfully used by vehicle designers, evaluators, procurers, deployers, and operations analysts.

Objective

This investigation was directed by TECOM as a result of recommendations made in the report[16] covering the earlier mobility investigations at USATTC. From these earlier studies, techniques for quantifying vehicular/vegetation interactions were recognized as requiring further development. Objectives of the present investigation were as follows:

- Evaluate subtests designed to measure the interaction of vehicles with tropic vegetation and suggest appropriate subtests for use in the conduct of tropic vehicular studies.

- Compile performance data from tests with several vehicles to obtain a data bank for future test reference.

- Provide test data for use by TACOM in the further verification and refinement of the AMC '71 Mobility Model.

- Develop procedures for the modification of Materiel Test Procedures 2-3-504 and 2-4-003: "Cross-Country Mobility" and "Wheeled, Tracked, and General Purpose Vehicles."

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[17] *Operation of Trucks in Tropical Climates and in Land and Desert Terrain*, September 1970.
[18] *The AMC '71 Mobility Model, Vol. I*, July 1973.
[19] *The AMC '71 Mobility Model, Vol. II*, July 1973.

DETAILS OF INVESTIGATION

General

A total of 345 mobility tests were conducted in the Canal Zone to evaluate the capabilities of standard military wheeled vehicles to override and maneuver through tropic vegetated areas. In the original plan, tracked vehicles were also to be evaluated but are not included because of readiness commitments of the host command. Details on types of tests conducted, procedures used, and results obtained are in the following paragraphs.

Description of Test Areas

All phases of the vehicular/vegetation tests were conducted during the rainy season in the USATTC Gamboa A-1 test area (figure 1), located in the middle of the Isthmus. Five test sites along Pipeline road (designated A through E in figure 1) were used for the grassland and tropic forest tests. These five sites were selected for relative uniformity of vegetation and terrain characteristics and lack of environmental extremes such as low soil strengths, slopes, and obstacles. The test sites were mainly level with greater than 90 percent of their area having less than a 2 percent slope. The boundaries of the individual test sites were defined by streams and sloping terrain.

Vegetation at all sites was characterized by Tropic Moist Forest as defined by the Holdridge Life Zone[20] system of classification. The vegetation in the area was approximately 30-year-old secondary growth. The few large emergent trees scattered throughout the test area were uncut remnants from a previous forest. Vegetation closest to Pipeline Road was primarily tropical grasses, *Gynerium sagittatum* (figure 2). This grass was a uniform 4 to 6 feet tall due to persistent cutting and/or burning. The vegetation farther from the road was a relatively uniform stand of advanced secondary growth 30 to 40 years old (figure 3). The tree species represented those normally associated with secondary growths, i.e., *Miconia* sp, *Apeiba* sp, *Annona* sp, *Luehea* sp, *Cochlospermum* sp, *Cecropia* sp, and *Guazuma* sp. A few mature forest species were present that will eventually form the character of the mature forest. These trees were generally young and had not yet attained their mature stature. The relative youth of the forest in this area provided an open canopy and subsequent dense undergrowth characterized by shrubs, herbs, and vines. The density of this undergrowth can provide sufficient mass to be an impediment to the movement of both man and vehicles due to its obscuration and mass.

In planning the single-tree failure and override tests, it was recognized that the proximity of trees and dense undergrowth would make it impossible to move the vehicles into position for tree failure force measurements for unobstructed single trees. To facilitate these problems, approach lanes were bulldozed into the jungle and the dense undergrowth removed by hand cutting as shown in figure 4. The test sites for the multiple-tree failure/override and vegetation maneuverability tests were altered only by bulldozing approach lanes to permit access to the test sites; the undergrowth was left undisturbed.

Soils in the test sites were very uniform and consisted primarily of fine-grained soils classified as MH under the Unified Soil Classification System (USCS).[21] The drainage

[20] *The Forest Environments in Tropical Life Zones,* Permagon Press, NY, 1971.

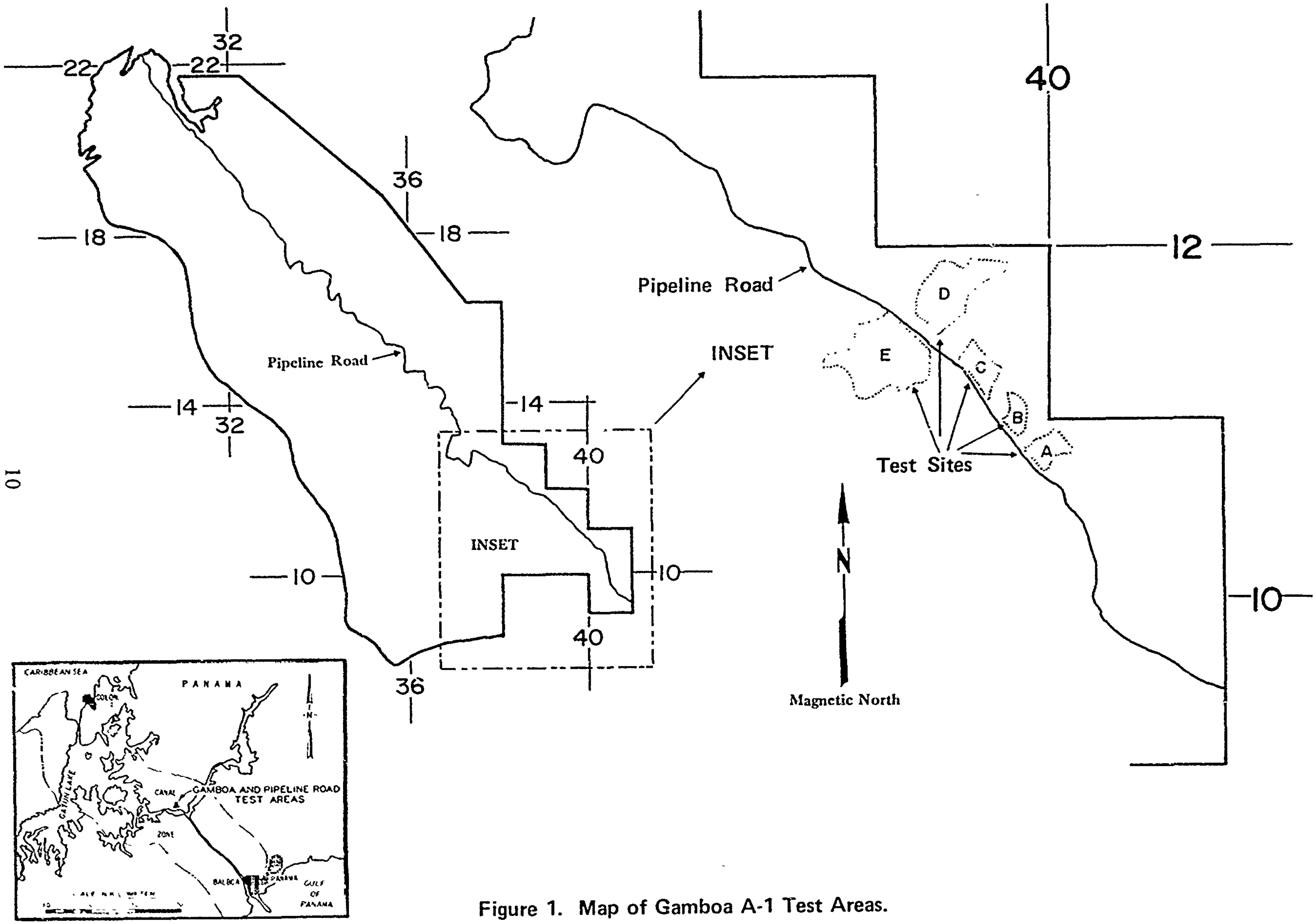


Figure 1. Map of Gamboa A-1 Test Areas.

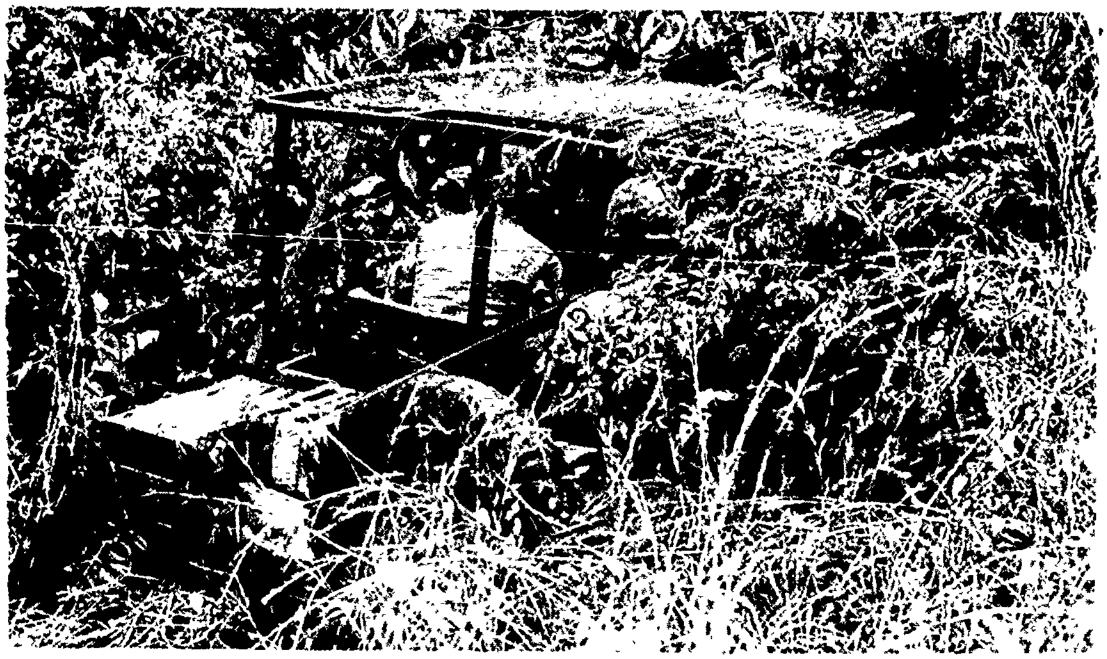


Figure 2. Grassland Area along Pipeline Road.

Figure 3. Secondary Vegetation Growth—30 to 40 Years Old.

a. Approach Lane for Single-Tree Failure/Override Tests.

b. Single-Tree Failure/Override Test Area Cleared of Dense Undergrowth.

Figure 4. Area Prepared for Single-Tree Failure/Override Tests.

within the test sites was such that inundation or puddling of water never occurred, hence soil strengths remained relatively stable throughout the year. Average cone index of the 0- to 6-inch layer was 240.

Types of Vehicles Tested

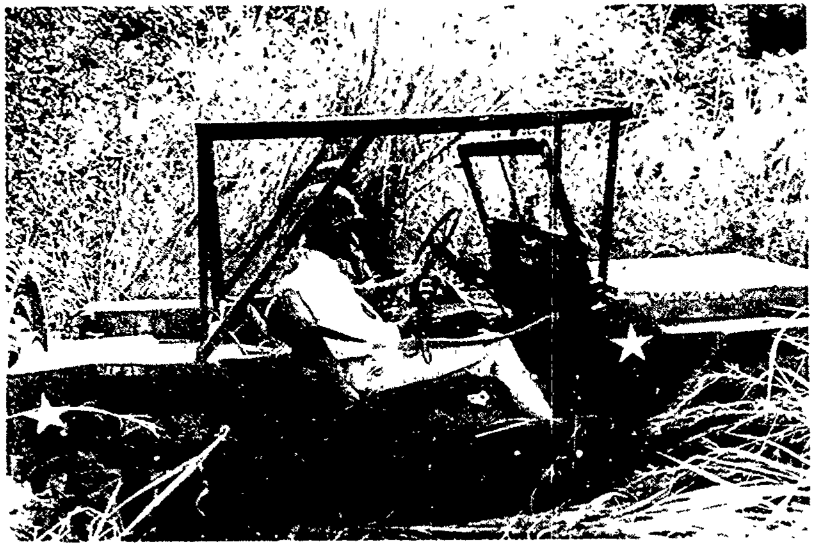
The vehicles used in this program were the (a) M151A1, ¼-ton truck; (b) M715, 5/4-ton truck; and (c) M36A2, 5/2-ton truck; general view of each is shown in figure 5 These vehicles were standard military vehicles with the exception that metal cages were added, as illustrated in figure 5a, to protect occupants from falling limbs, etc. A listing of the physical characteristics of each vehicle, pertinent in mobility analyses, is shown below.

Table 1. Vehicle Characteristics

Characteristics / Type of Vehicle	M151A1, ¼-Ton without Winch	M715, 5/4-Ton with Winch	M36A2, 5/2-Ton with Winch
Vehicle Weight—Empty (pounds)	2,400	6,000	15,750
Cross-Country Payload with Personnel (pounds)	800	2,500	5,000
Tires			
—Number	4	4	10
—Size	7.00 x 16	9.00 x 16	9.00 x 20
—Tread Type	Nondirectional Cross-Country	Nondirectional Cross-Country	Nondirectional Cross-Country
—Ply Rating	6	8	8
—Tire Pressure (psi)	Front—20 Rear—20	Front—25 Rear—45	Front—35 Rear—35
Engine			
—Type	Gasoline	Gasoline	Multi-fuel
—Brake Horsepower	71 @ 4000rpm	132 @ 4000rpm	140 @ 2600rpm
—Transmission	Mechanical	Mechanical	Mechanical
Bumper Height (inches)*	20	24	34
Ground Clearance (inches)†	9	10	12
Dimensions			
—Length (inches)	132	221	224
—Width (inches)	63	85	96
—Height (inches)	53	95	124
Tractive Force (pounds)‡	2,195	7,460	12,340
One-Pass Vehicle Cone Index§	21	29	28

* Height measured from ground to bottom of bumper.
† Vehicle loaded to cross-country load limit.
‡ Tractive force shown based on drawbar pull at 20 percent slippage on paved surface.
§ Minimum soil strength required to enable vehicle to transit a level area one time.

[21] USAWES, *The Unified Soil Classification System*, Tech Memo No. 3-357, Vol. 1, March 1953 (Revised April 1960).



a. M151A1, ¼-Ton Truck with Protective Cage.

b. M151A1, ¼-Ton Truck.

c. M715, 5/4-Ton Truck.

d. M36A2, 5/2-Ton Truck.

Figure 5. Types of Vehicular Equipment Used in Test Program.

Types of Tests Conducted

Seven different types of vehicular mobility tests were conducted during the course of this methodology investigation. These tests are summarized in table 2.

Table 2. Types and Number of Tests Completed

Type of Test \ Type of Vehicle	M151A1, ¼-Ton Truck	M715 5/4-Ton Truck	M36A2 5/2-Ton Truck	Total for Each Type of Test
Single-Tree Failure	37	39	39	115
Single-Tree Override	32	32	36	100
Multiple-Tree Failure	4	3	3	10
Multiple-Tree Override	4	3	3	10
Grassland Penetration	5	4	4	13
Maneuverability				
—Tropic Forest	10	8	10	28
—Grassland	3	3	3	9
Vehicle Motion Resistance	12	22	26	60
Total for Each Type of Vehicle	107	114	124	345

Vehicular Load Conditions

During testing the vehicles were loaded with concrete blocks up to their cross-country payload as specified by technical manuals applicable to each vehicle (table 1). Cargo loading was such that practically no weight shift occurred even under the most rigorous test conditons. Vehicle curb weights were determined from measured weights of the loads and published gross weights of the vehicles. Tire pressures for cross-country driving were verified by the driver during his daily organizational maintenance schedule.

Test Procedures

Single-Tree Failure and Override Tests. These tests evaluated the forces required of standard military vehicles to fail and override single trees characteristic of tropic forested areas. Since a driver would rarely attempt to override a tree standing alone—he would simply detour around—the primary purpose of these tests was to verify and refine the AMC '71 Mobility Model. The validation and refinement of this model for particular application in tropic regions of the world provide developers with a sound basis for a comprehensive analytical model of vehicle performance.

The tests were conducted by measuring the forces required by each vehicle to first fail a tree and then to override it. Prior to each test, individual drivers were thoroughly oriented on procedures to be followed as discussed in the following paragraphs.

First the test site was cleared of all undergrowth and an approach lane bulldozed into the jungle, as illustrated in figure 4. Measurements were then made of environmental parameters considered pertinent to the tests being conducted; i.e., tree type; branching height; tree height; crown diameter; stem diameter at breast height (DBH); stem basal diameter; and cone indices of the 0- to 6-inch and 6- to 12-inch, and 12- to 18-inch soil layers. In addition, bulk soil samples were collected from the 0- to 6-inch and 6- to 12-inch layers for soil type classification and moisture content measurements. Remarks as to any unusual environmental circumstances were also recorded. Examples of data measurements being taken in the field are illustrated in figure 6.

After collection of these data, the test vehicle was maneuvered into a position to center the test tree against its front bumper and be in line with a second vehicle whose winch would be used to pull the test vehicle over the test tree (figure 7).

The cable from the winch of the second vehicle was then connected to the front bumper of the test vehicle through a V-shaped arrangement that permitted even pull on both shackles of the front bumper without interfering with failure of the tree. A 20,000-pound load cell was spliced into the winch cable to obtain a measure of the forces being exerted on the test vehicle as it was winched over the tree. The driver of the test vehicle then placed his vehicle in all-wheel drive and shifted the transmission into neutral position. The test vehicle was then winched until the tree failed due to root or stem failure, or until the tree was pushed down due to bending. At this point the tree was considered failed, and the distance that the test vehicle had moved was recorded for use in computing the total work required to fail the tree. During this winching action, continuous recordings of the forces being exerted through the load cell were made using the instrumentation shown in figure 8.

The winching action was initiated again, and recordings were made of forces being exerted through the winch cable until the test vehicle had cleared the branches of the failed tree. The distance the test vehicle had moved from the point of tree failure until clearing the tree crown was recorded for total work computations, as discussed in the previous paragraph.

Typical views of the test vehicle failing and overriding a tree are shown in figure 9.

Multiple-Tree Failure/Override Tests. These tests were designed to investigate the relation between single-tree and multiple-tree failure and override forces. The primary difference between the multiple- and single-tree tests was that, in multiple-tree tests, failing of any one tree was interfered with by neighboring trees due to crown entanglement and vines. The positioning and winching of the test vehicle in these tests was the same as described in previous paragraphs covering single-tree failure/override tests. Test sites used in this phase of testing were selected with tree sizes appropriate to the vehicle being tested as determined by single-tree failure data. A view of a typical multiple-tree failure/override test being conducted is shown in figure 10.

a. Measurement of Cone Index.

b. Measurement of Diameter of Tree at Breast Height.

Figure 6. Environmental Measurements in Progress for Single Tree Failure/Override Tests.

Figure 7. M715, 5/4-Ton Truck, Positioned for Single-Tree Failure/Override Test.

Grassland Penetration Tests. These tests were designed to determine the motion resistance imposed by tropic grassland areas to vehicular movement. The test vehicles were again positioned and winched as described in the single-tree failure/override tests. Environmental data were recorded on such factors as stem density and cone indices. Bulk soil samples were analyzed for soil type classification and moisture content. After these data had been collected, the vehicle was winched through the undisturbed grass area with force and distance measurements being recorded. The vehicle was then returned to the starting point and again winched through the same path with the grass already flattened by the initial pass of the test vehicle. A typical view of a test vehicle entering a grassland test area is shown in figure 11.

Tropic Forest Maneuverability Tests. These tests were designed to determine the capability of standard military vehicles to progress through uncleared tropic forested areas. The information gathered during these tests was used to identify the limits of vegetation undergrowth and stem spacing of trees on vehicular mobility. Vehicle drivers operated within defined test site boundaries but were allowed to maneuver (stop, back-up, go forward, or turn) at will in their attempts to traverse an area. Each test was considered completed when the area was traversed or the test vehicle was stopped by damage or vegetation. Test sites used in this phase of the study were chosen so that variations in other environmental parameters, such as soil strength and topography, were not confounded with vegetation effects.

In the conduct of the tests, the driver approached the test site through approach lanes bulldozed into the jungle, as discussed earlier. He was instructed as to the general direction in which to drive and was told to traverse the area as far as possible or until he

a. Load Cell on Cable between Winching Vehicle and Test Vehicle.

b. Data Processing/Recording Equipment in Rear of Vehicle.

Figure 8. Instrumentation Used in Failure/Override Tests.

a. Position of Vehicle in Early Stage of Tree Failure.

b. Vehicle at Base of Tree in Tree Override Test

c. Vehicle Nearing Crown of Tree in Tree Override Test.

d. Vehicle Nearing Completion of Tree Override Test

Figure 9. Illustrating Various Stages of Tree Failure/Override Test.

Figure 10. M151A1, ¼-Ton Truck Entering Multiple-Tree Failure/Override Test Area.

Figure 11. M151A1, ¼-Ton Truck Entering a Grassland Test Area.

reached an approach lane on the opposite side of the test area. Speed and direction of travel were left to his discretion with the exception that he was instructed to move through the area as fast as he considered safe. The driver then drove into the jungle and progressed as far as possible. As he moved through the jungle, the number of times that he stopped and backed up to maneuver around trees, the total transit time, and the distance travelled were recorded using a 5th-wheel, time generator and magnetic tape recording system. At the point where a vehicle was immobilized, the reason (type, spacing, and stem diameter of vegetation; obstacle; or vehicle damage) was noted. The path that the vehicle had traversed was then characterized with regard to soil type, moisture content and strength, and minimum spacing of trees. Descriptions of vegetative undergrowth were also made. Any trees overriden during the experiment were considered part of the undergrowth.

The course traversed by the vehicle was then cleared of all undergrowth, and the test vehicle returned along the same path as rapidly as the driver considered safe. During this portion of the test, travel time out was recorded for comparison with travel time in.

Figures 12 through 14 show typical views of test areas, vehicular damage during tests, and characteristics of vegetation that halted vehicular movement through the test areas.

Tropic Grassland Maneuverability Tests. Objective of these tests was to determine the extent to which tropic grasslands impeded the movement of vehicles. The tests were conducted in the same manner as described for maneuverability through forests, but test areas contained only grass and a few small shrub-type plants. Although no vehicular damages were sustained during this phase of testing, figure 15 illustrates a potential hazard causing overheating of vehicles during and after prolonged travel through tropic grasslands.

Vehicle Motion Resistance. Test objective was to obtain a measure of the force required to overcome the motion resistance of the vehicle. The tests were conducted in the same areas as the single-tree failure/override tests with all vegetation removed from the path of the vehicle. The instrumentation and procedures described earlier for single-tree failure/override tests were used in this phase of testing.

a. Undisturbed Tropic Forest Test Area

b. Looking Out from Jungle along Path Traversed by Test Vehicle during Tropic Forest Tests.

Figure 12. Typical Views of Tropic Forest Maneuverability Test Areas.

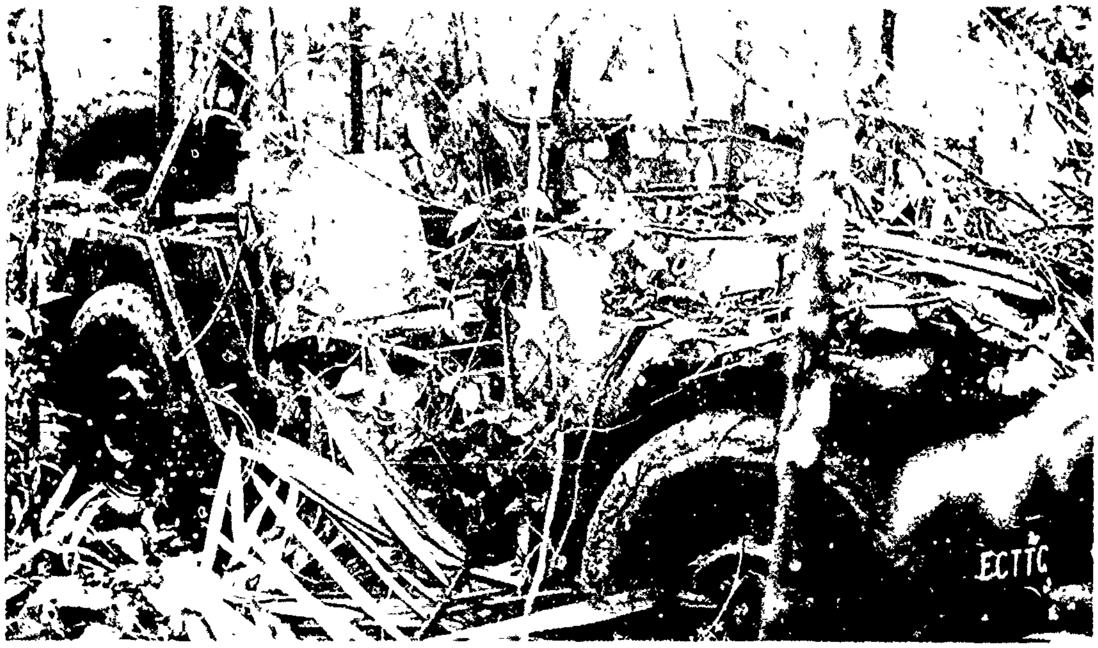
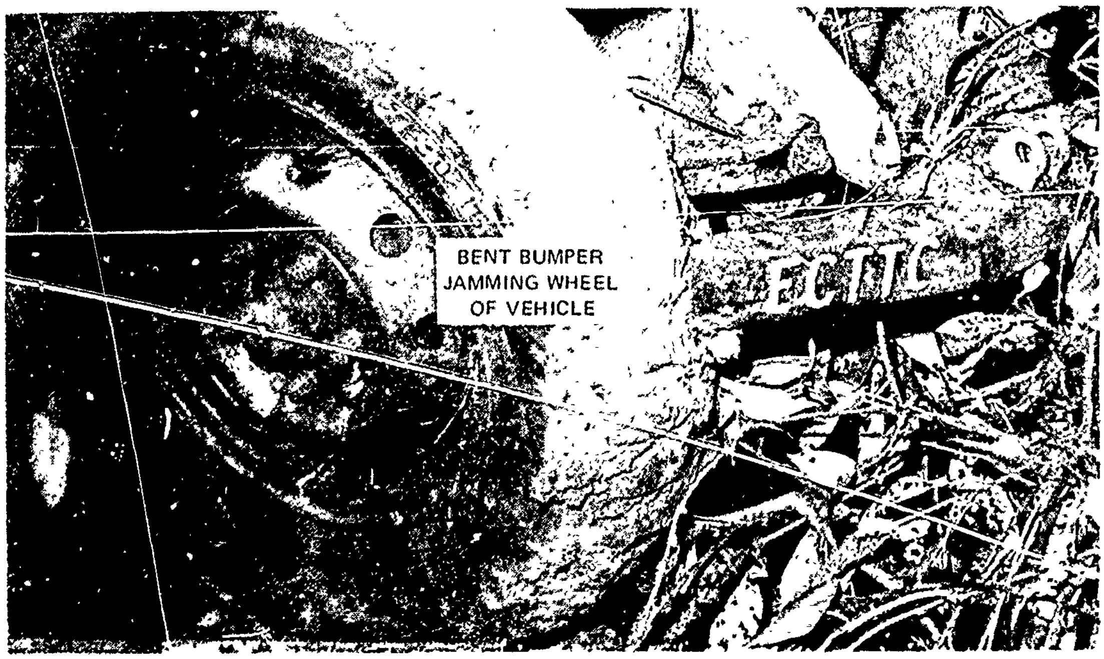


Figure 13. Side and Front View of M151A1, ¼-Ton Truck Stopped by Vegetation during Tropic Forest Maneuverability Tests.

a. M151A1, ¼-Ton, Truck Entangled in Vegetation.



b. Damage To Vehicle Resulting in Stoppage.

Figure 14. Vegetation Entanglement and Vehicular Damage Resulting in Stoppage during Tropic Forest Maneuverability Tests.

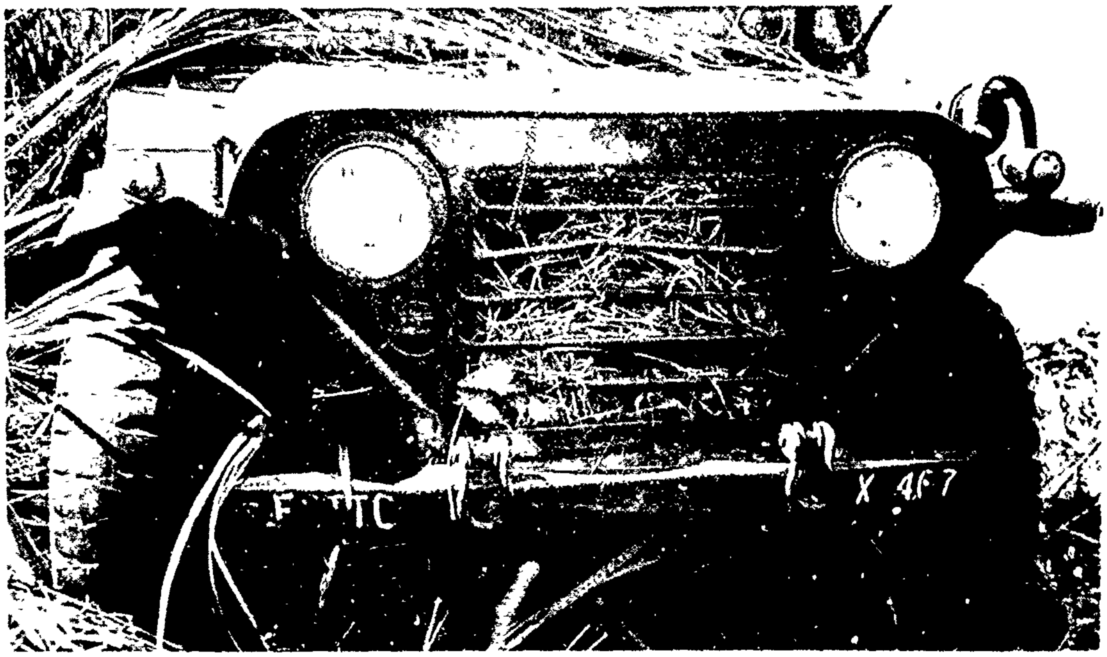


Figure 15. Grass Embedded in Radiator of M151A1, ¼-Ton Truck.

ANALYSIS AND RESULTS OBTAINED

General

Results of these studies and methods of analysis used are discussed in the following paragraphs. A summary of results, tables D-1 through D-5, provides the following applicable data, (a) vegetation characteristics including type, stem diameter, basal diameter, tree height, crown diameter, branching height, and stem density, (b) soil characteristics including USCS soil type classification in the 0- to 6-inch and 6- to 12-inch layers, and cone indices in 6-inch layers to a depth of 18 inches; (c) mode of failure of a tree; (d) reason for immobilization of the vehicle; (e) remarks regarding pertinent test anomalies; and (f) major vehicle test results.

Single-Tree Failure Tests

Results obtained in this phase of testing are listed in table D-1 with methods of analysis discussed below.

The first step, in the search to establish mathematical relations describing the force required by a vehicle in order to fail a tree, was to find environmental parameter(s) which would show the best correlation with the measured forces. This was done by studying (a) scatter diagrams illustrating the relation between the various environmental parameters measured and the forces required to fail a tree, and (b) correlation matrices produced by a multiple linear regression analysis. The environmental parameter with the highest correlation was found to be tree stem diameter as measured at breast height.

In an effort to use this parameter in establishing mathematical relations, it was understood that a portion of force required to fail a tree would be caused by motion resistance of the vehicle itself. These motion resistances were measured during separate tests, described earlier, and are summarized in table 3.

Table 3. Summary of Motion Resistance Test Results

Data Obtained \ Type of Vehicle	M151A1 ¼-Ton Truck	M715 5/4-Ton Truck	M36A2 5/2-Ton Truck
Mean Motion Resistance (pounds)	365	930	1735
Standard Error of Estimate	65	206	297
Range of Values	300–500	600–1500	1400–2500
Number of Tests Conducted	12	22	26

Multiple regression analysis showed that the following formula best predicted the total forces:

$$F = F_o + ad^b \qquad (1)$$

where F equals the total force needed to fail a tree, F_o equals the force required to overcome motion resistance, d equals stem diameter, and a and b are empirical constants. The formulae generated for the force required to fail a single tree were as follows:

$$F = 365 + 197d^{2.03} \quad \text{M151A1, ¼-ton truck} \qquad (2)$$

$$F = 930 + 319d^{1.65} \quad \text{M715, 5/4-ton truck} \qquad (3)$$

$$F = 1735 + 356d^{1.73} \quad \text{M36A2, 5/2-ton truck} \qquad (4)$$

Plots of curves generated from these formulae along with their correlation coefficients and 90 percent predictive intervals are shown in figures 16 through 18. In development of these formulae, consideration was given to the maximum force (tractive force) that each vehicle could produce. Because of the manner in which these tests were conducted (winching of vehicles as opposed to self-propelled action), it was possible that some of the trees failed would not be failed if the vehicles developed forces by a self-propelled action. In the case of the 5/4- and 5/2-ton trucks, winching introduced no problems since the tractive forces produced by these vehicles are sufficient to fail all trees tested with a minimum amount of additional force required from the inertia of the vehicles. In the case of the ¼-ton truck, however, the tractive force is relatively small, and only those trees that could be failed with the vehicle travelling at a maximum speed of 5mph were considered in development of the force equation. This speed was judged the maximum at which a driver would attempt to override a tree—taking into account his personal safety.

After development of these equations for each vehicle, an attempt was made to develop a general equation suitable for use for all three vehicles. Using all data and the individual F_o values for the three vehicles, the following formula was found to yield the best fit:

$$F = F_o + 285d^{1.79} \qquad (5)$$

Plots of this general equation are shown in figures 19 through 21. Examination of the standard error of estimate values obtained, using this general equation as opposed to the equations developed for each individual vehicle, yielded only small differences. These small differences are also noticeable when comparing the correlation coefficients.

Single-Tree Override Tests

In development of mathematical relations describing the capability of standard military vehicles to travel through vegetated areas, the capability of a vehicle to fail a tree is of little importance unless the vehicle can then crush the branches of the tree and develop sufficient force to override the tree (clear the trunk and crown). Table D-1 summarizes the results of tests conducted to override trees with the M151A1, ¼-ton truck, M715, 5/4-ton truck; and M36A2, 5/2-ton truck. Using the computerized

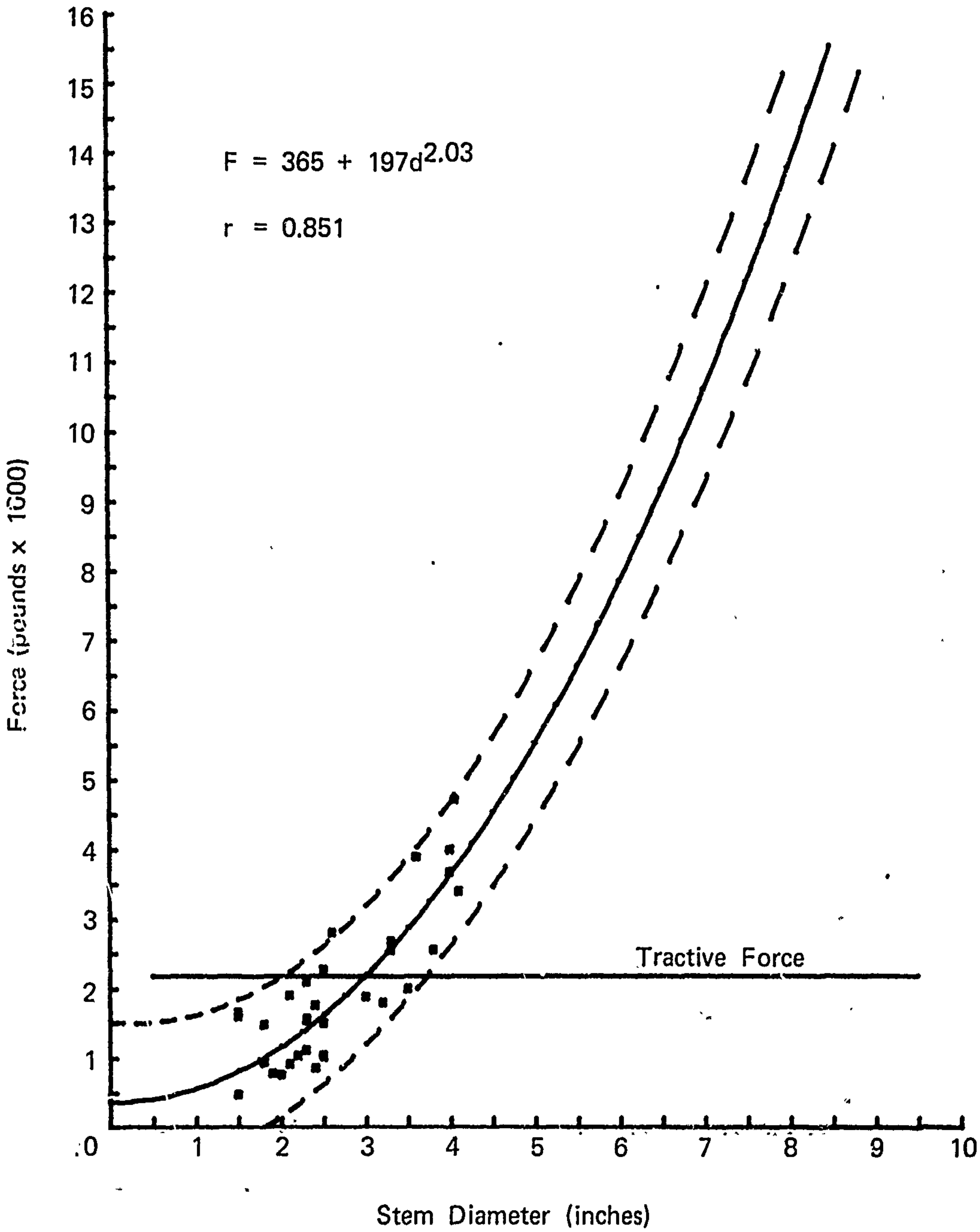


Figure 16. Force Required to Fail a Tree with M151A1, ¼-Ton Truck.

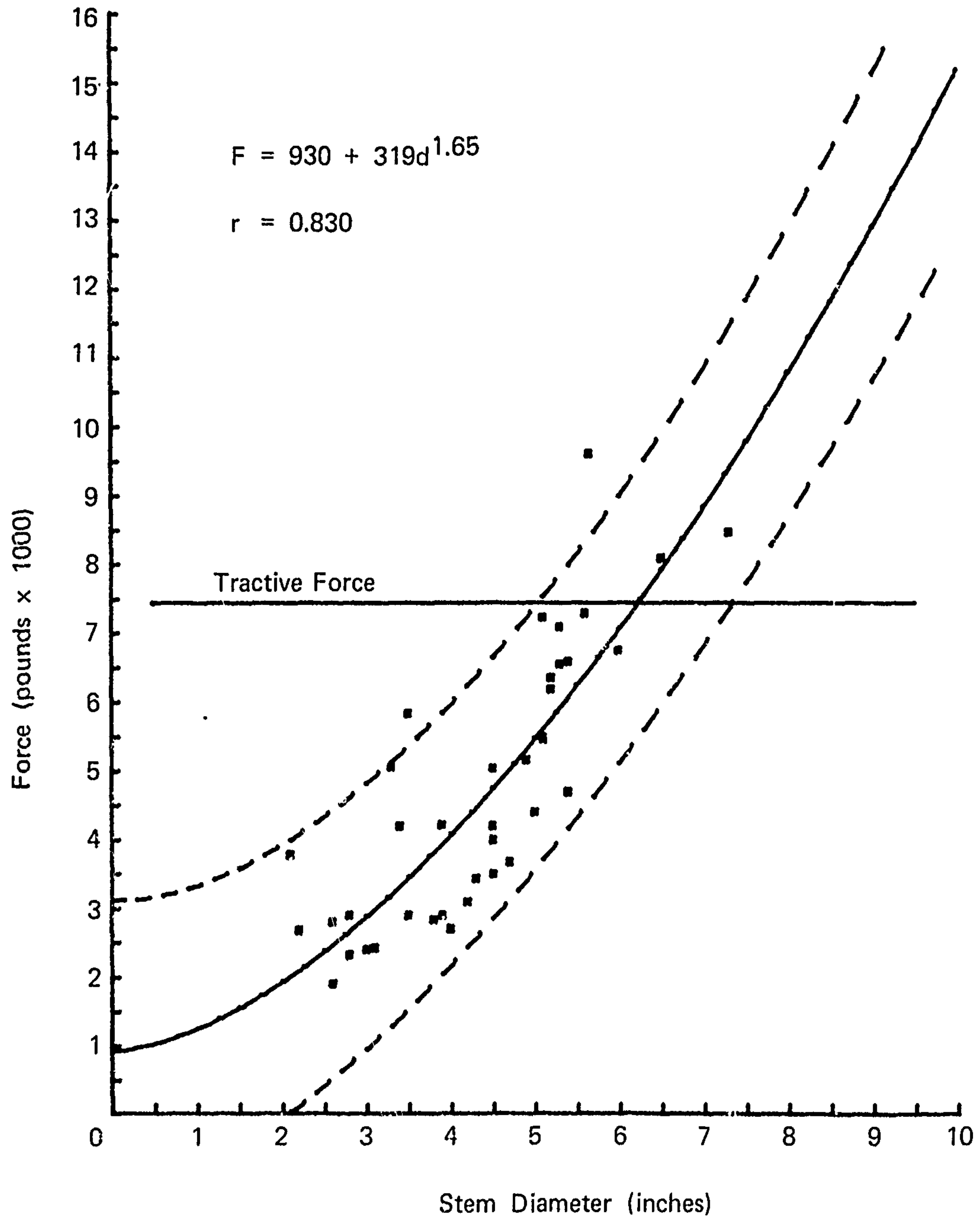


Figure 17. Force Required to Fail a Tree with M715, 5/4-Ton Truck.

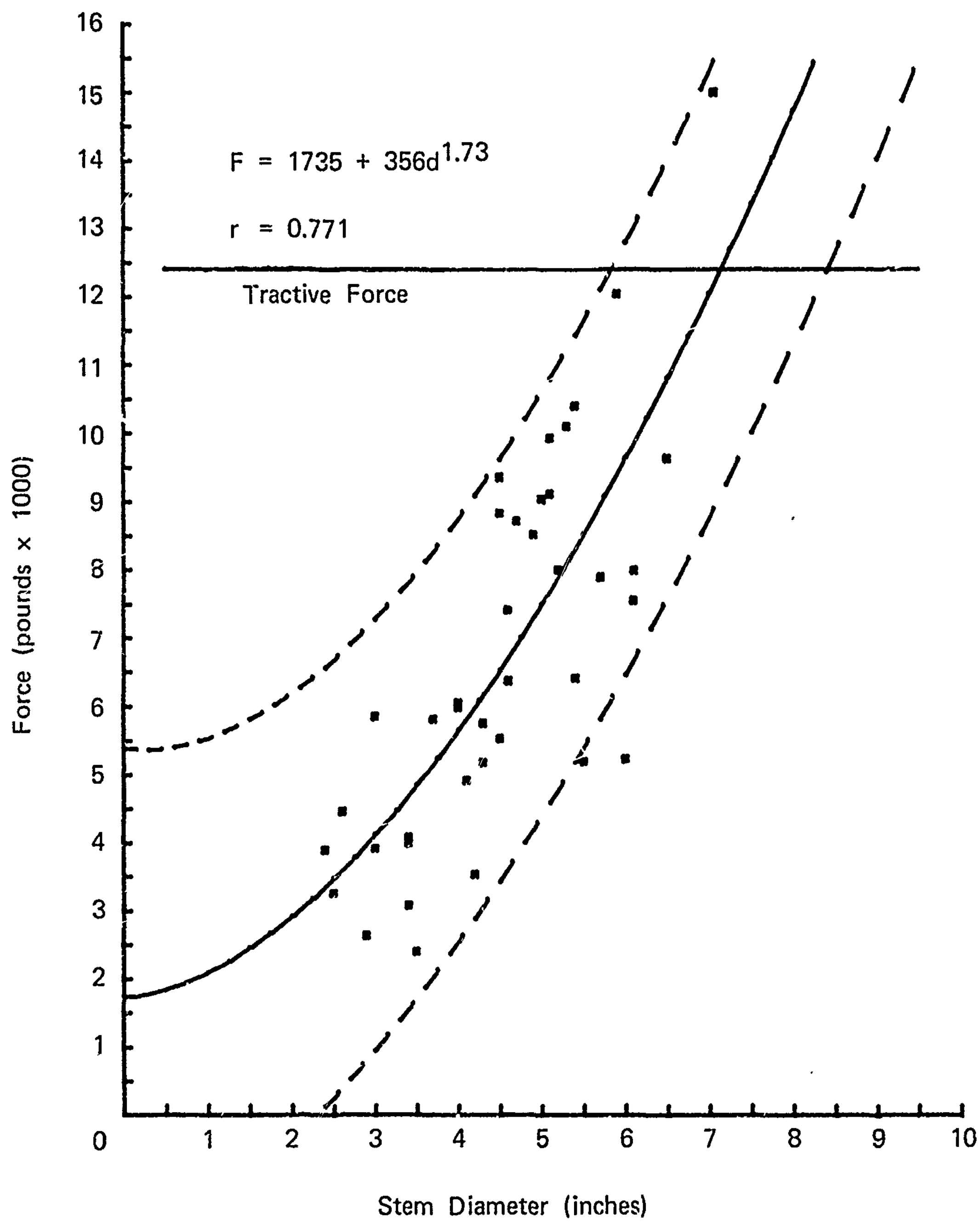


Figure 18. Force Required to Fail a Tree with M36A2, 5/2-Ton Truck.

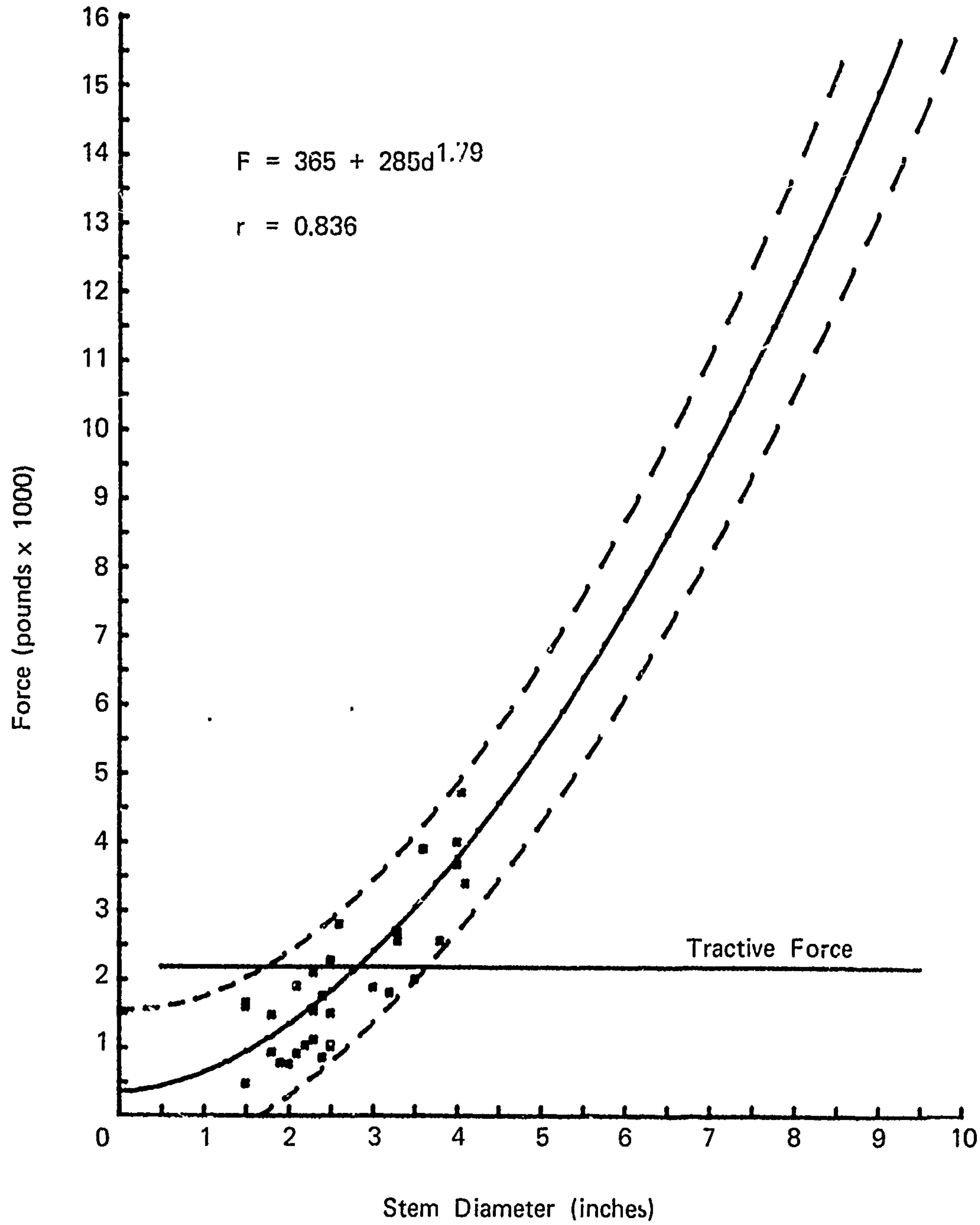


Figure 19. Force Required to Fail a Tree with M151A1, ¼-Ton Truck (from General Equation).

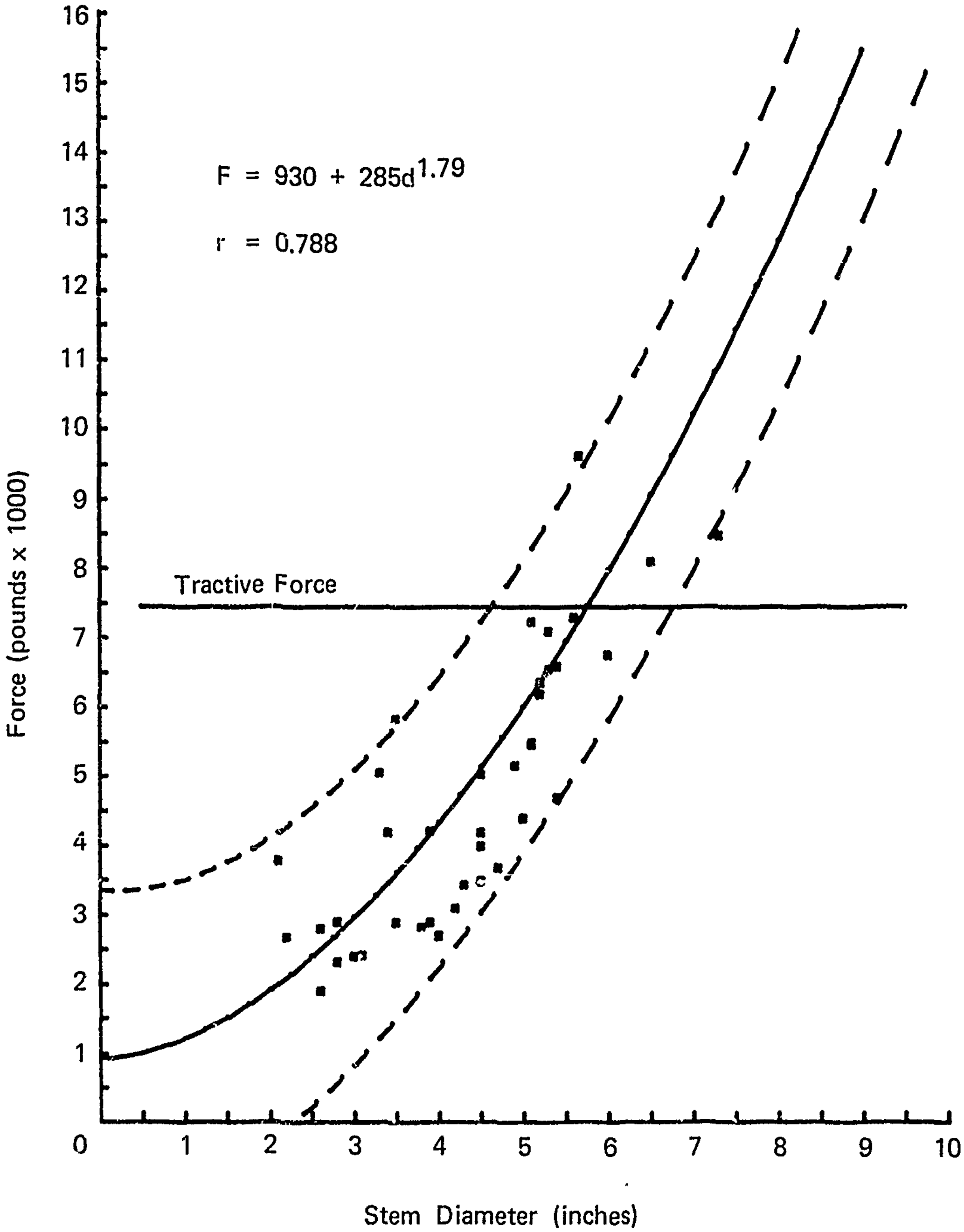


Figure 20. Force Required to Fail a Tree with M715, 5/4-Ton Truck (from General Equation).

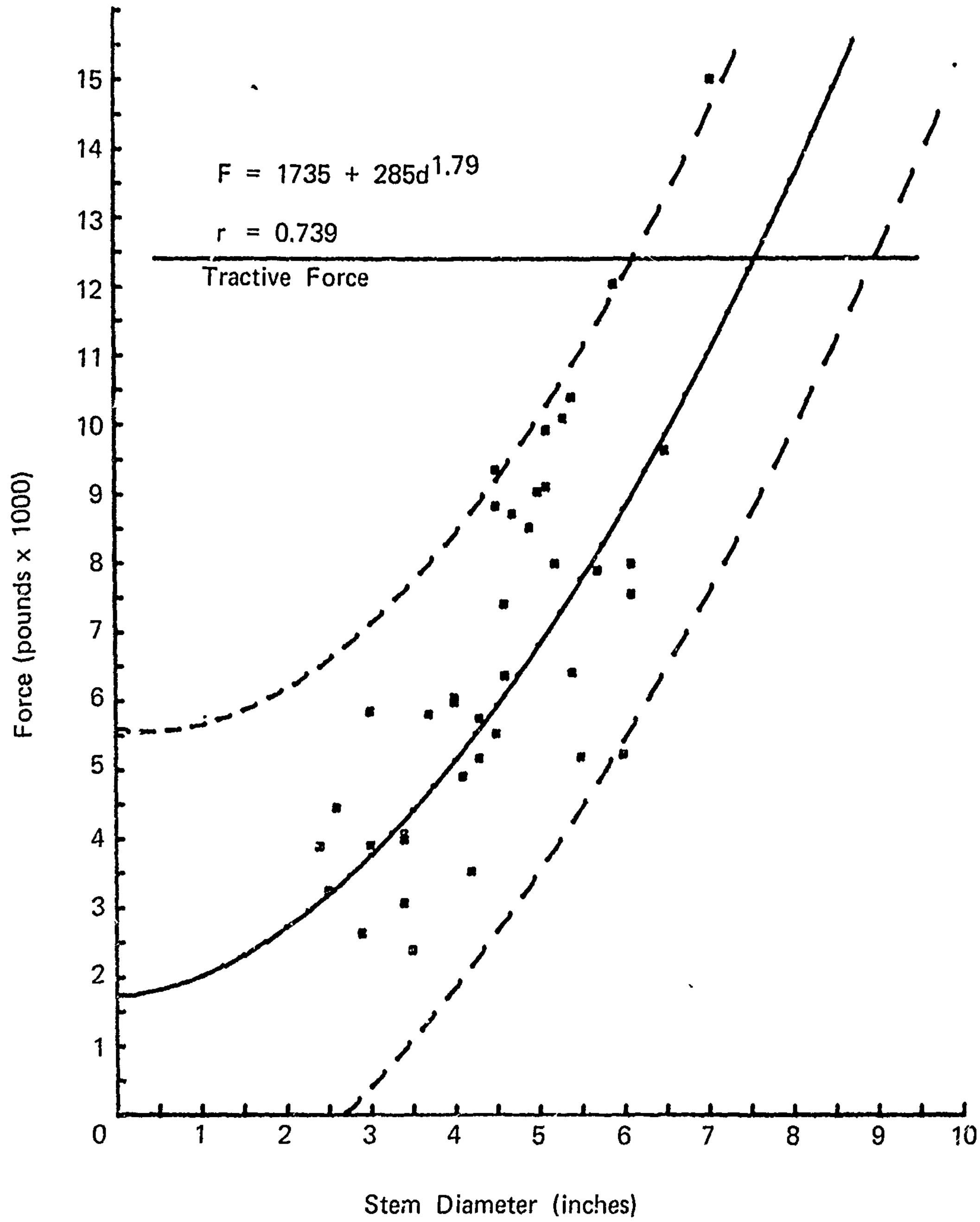


Figure 21. Force Required to Fail a Tree with M36A2, 5/2-Ton Truck (from General Equation).

techniques described previously for single-tree failure tests, the following equations were developed for the forces required to fail and override single tropic trees.

$$F = 365 + 200d^{2.02} \quad \text{M151A1, ¼-ton truck} \quad (6)$$

$$F = 930 + 303d^{1.71} \quad \text{M715, 5/4-ton truck} \quad (7)$$

$$F = 1735 + 472d^{1.55} \quad \text{M36A2, 5/2-ton truck} \quad (8)$$

Plots of these formulae along with their correlation coefficients and 90-percent prediction intervals are shown in figures 22 through 24. In development of these equations the maximum force measured in either fail or override tests was used, since both must be considered if a vehicle is to be capable of overriding a tree. The work (force multiplied by distance) required to override a tree was not taken into consideration in development of these equations, because it was assumed that if a vehicle is capable of producing the force required to fail and/or override a tree, the distance the force is exerted is of no practical importance.

Again, an attempt was made to develop a general equation that would be suitable for use for all three vehicles. Using all data and the individual F_o values for the three vehicles, the following formula was found to yield the best fit:

$$F = F_o + 318d^{1.74} \quad (9)$$

Plots of this general equation are shown in figures 25 through 27. Again, examination of the standard errors of estimate and correlation coefficients obtained using this general equation as opposed to the equations developed for each individual vehicle reflects only small differences.

Multiple-Tree Failure/Override Tests

In the test area, vines entangle the branches of adjoining trees and the crown and trunk of one tree interferes with the felling of another tree nearby. Also, because the underbrush and trees were not thinned out as in the single-tree failure/override tests, more than one tree might be encountered at the same time as the vehicles traversed the test course. This is illustrated in figure 28 which shows the number, type, and size of vegetation along a typical test course.

The results obtained in the multiple-tree failure/override tests are contained in table D-2. In order to compare the force required to fail and override a single tree versus that required to fail and override multiple trees, the effective stem diameter of the trees encountered along the test course was computed as shown in figure 28. The average stem diameter for each course was then computed and, together with equations 6 through 8, the force required to override single trees having the same stem diameter were computed. A graph comparing the values obtained is in figure 29. This plot shows that only approximately 10 percent more force is required to override multiple trees than single trees.

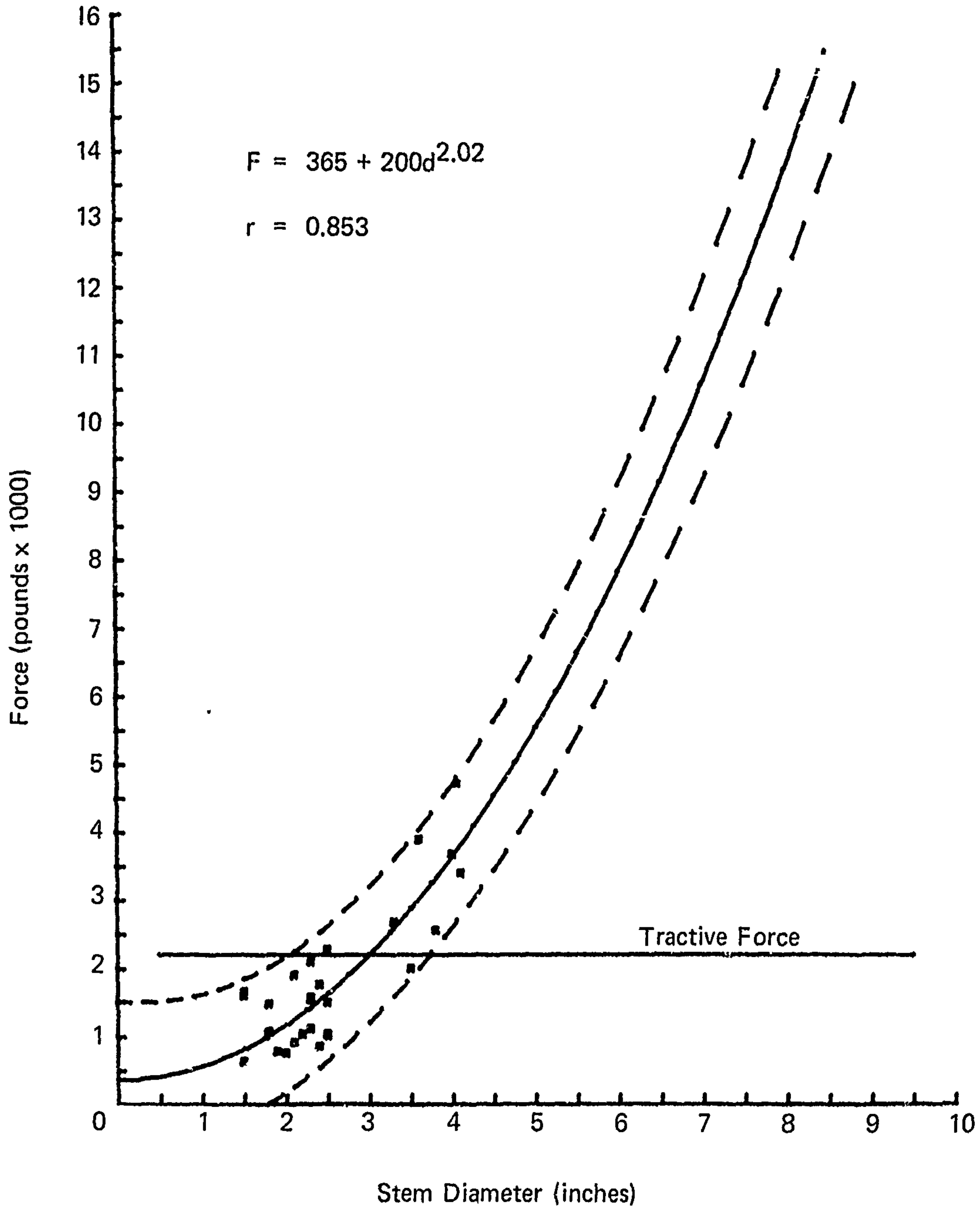


Figure 22. Force Required to Fail and Override a Tree with M151A1, ¼-Ton Truck.

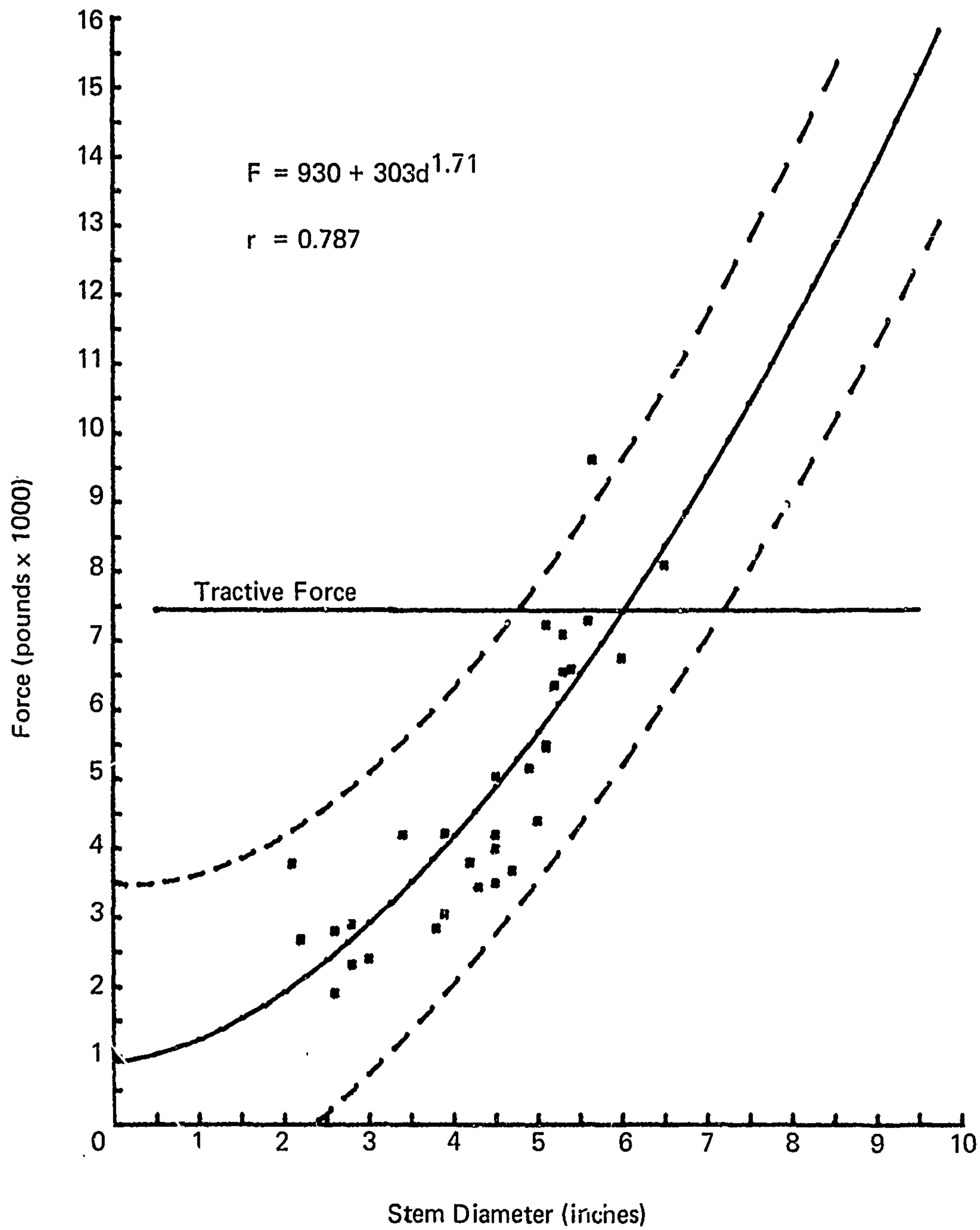


Figure 23. Force Required to Fail and Override a Tree with M715, 5/4-Ton Truck.

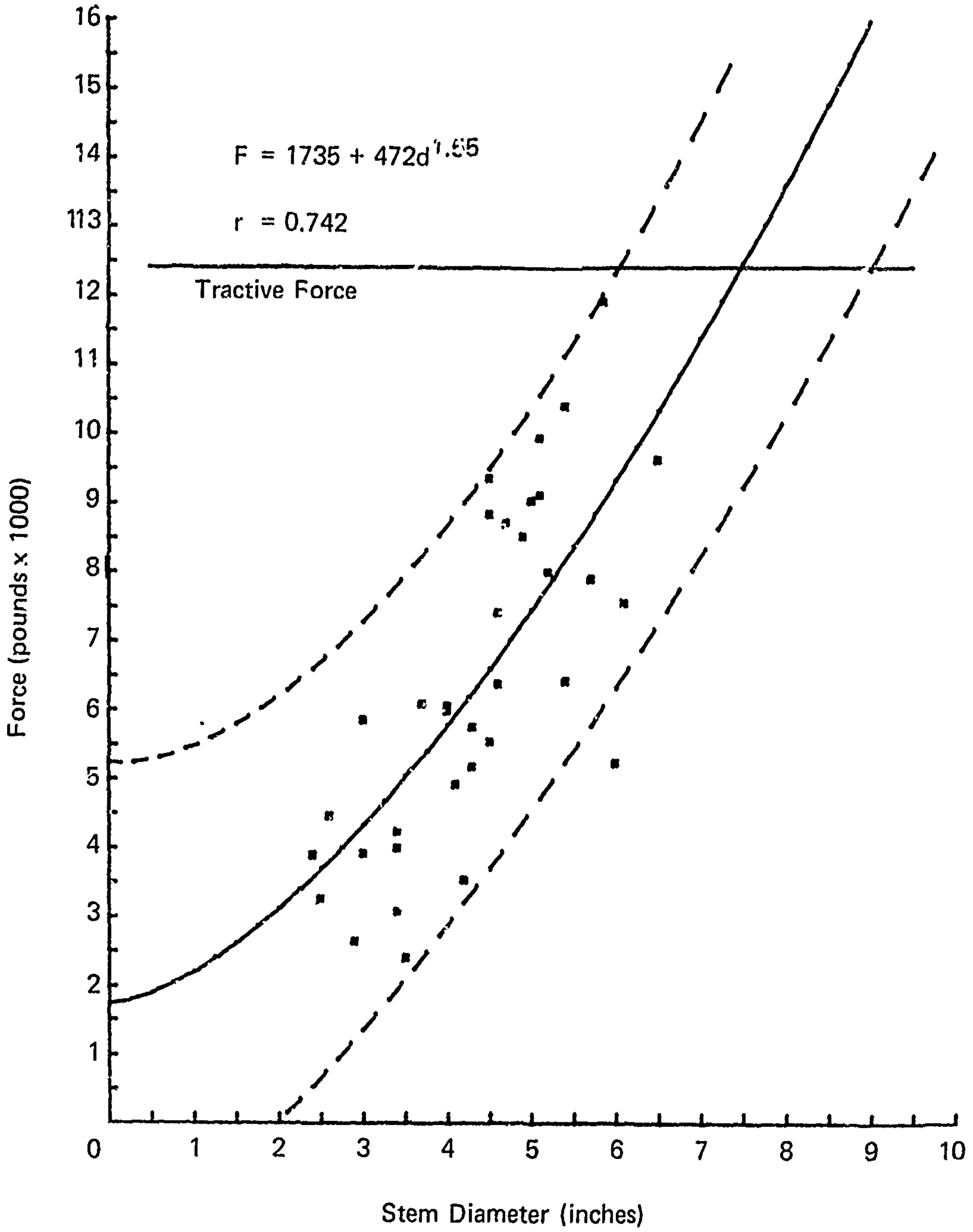


Figure 24. Force Required to Fail and Override a Tree with M36A2, 5/2-Ton Truck.

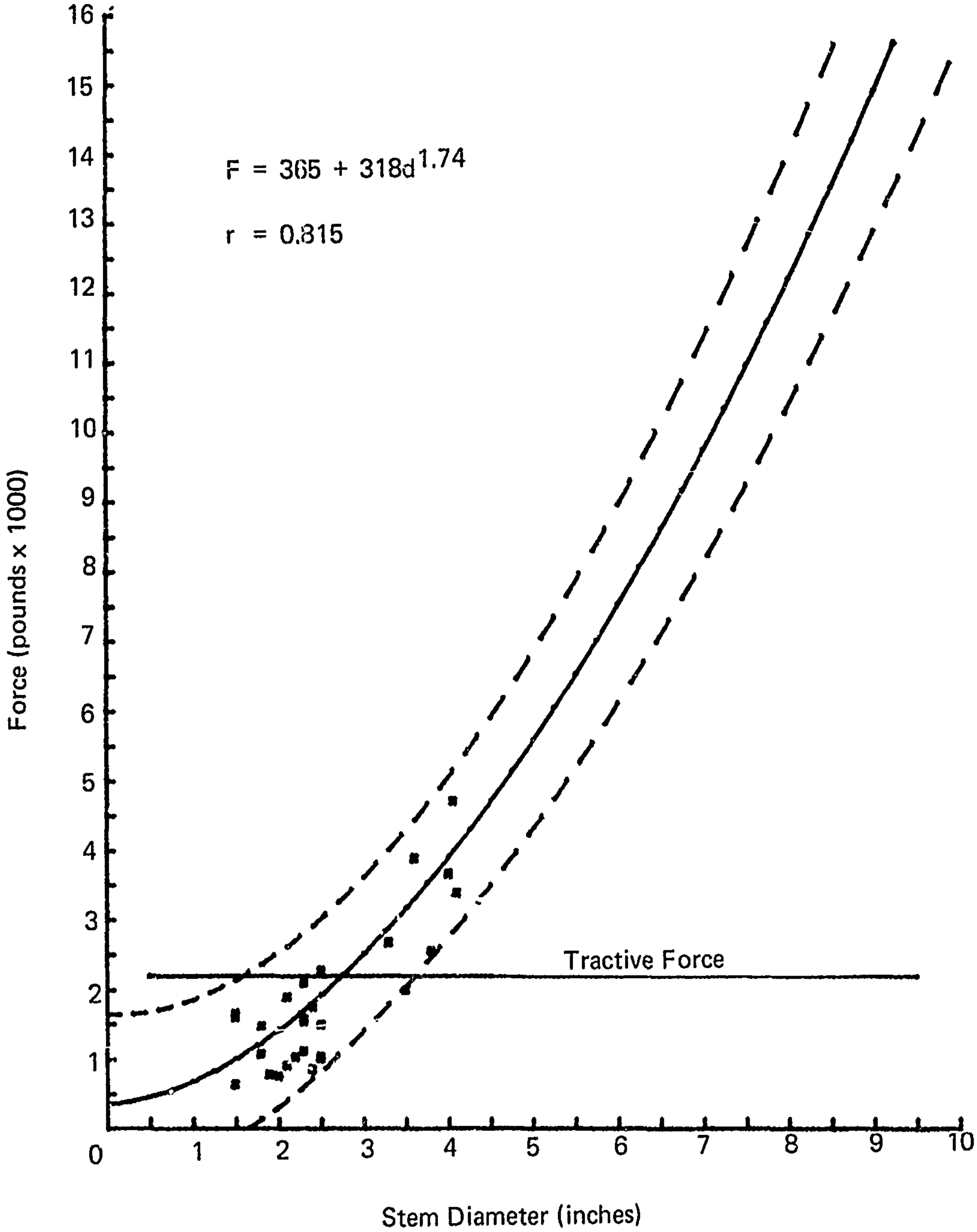


Figure 25. Force Required to Fail and Override a Tree with M151A1, ¼-Ton Truck (from General Equation).

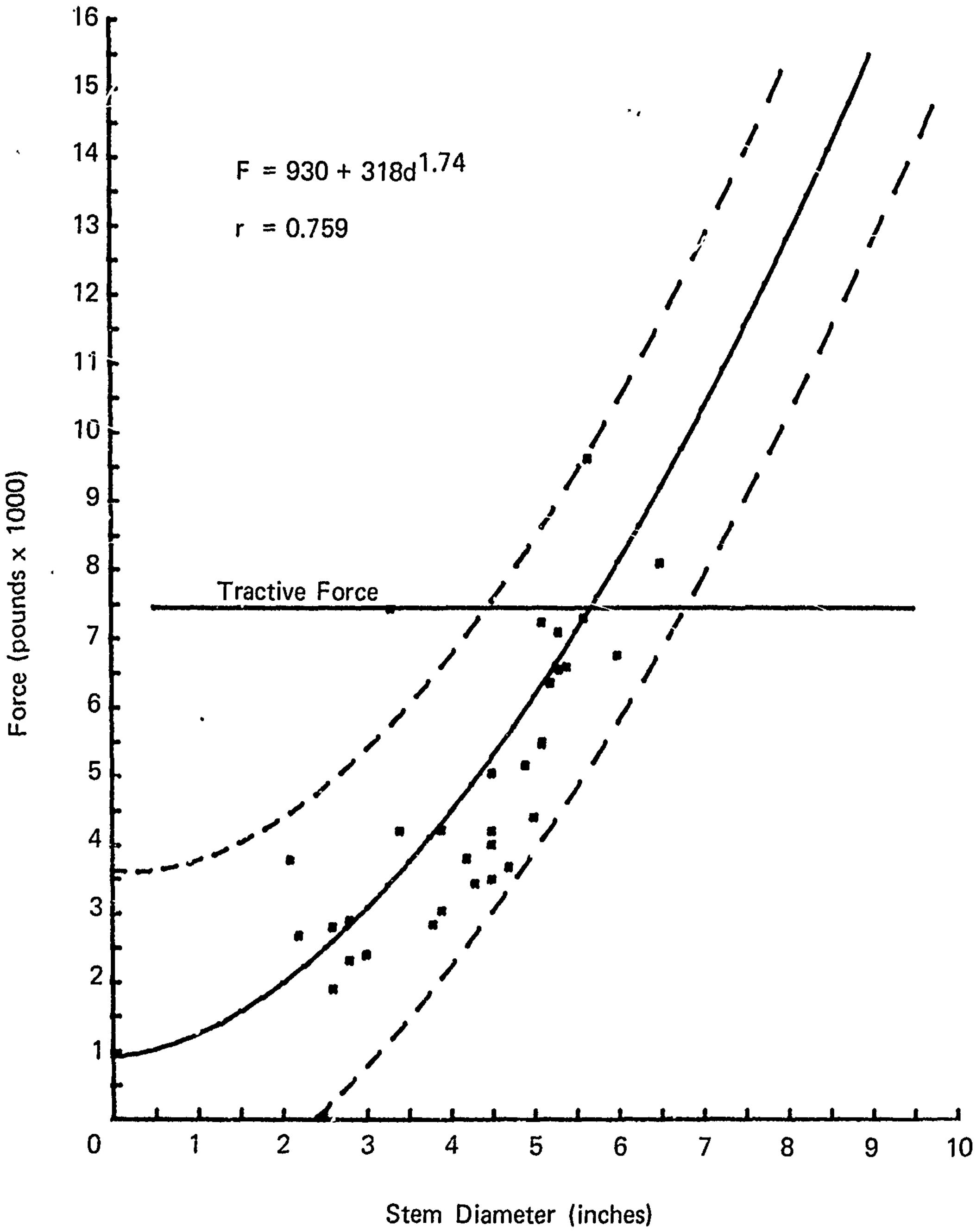


Figure 26. Force Required to Fail and Override a Tree with M715, 5/4-Ton Truck (from General Equation).

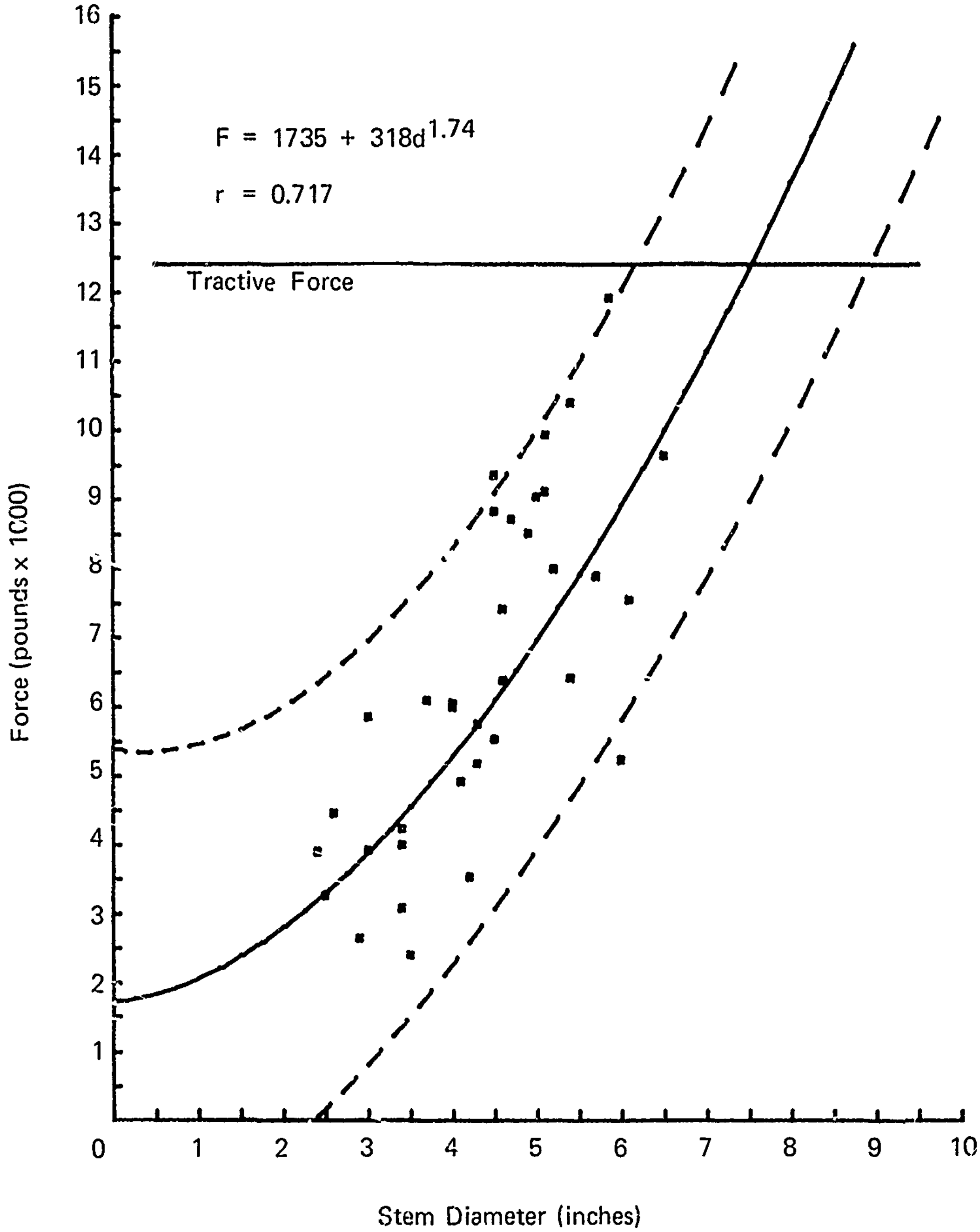
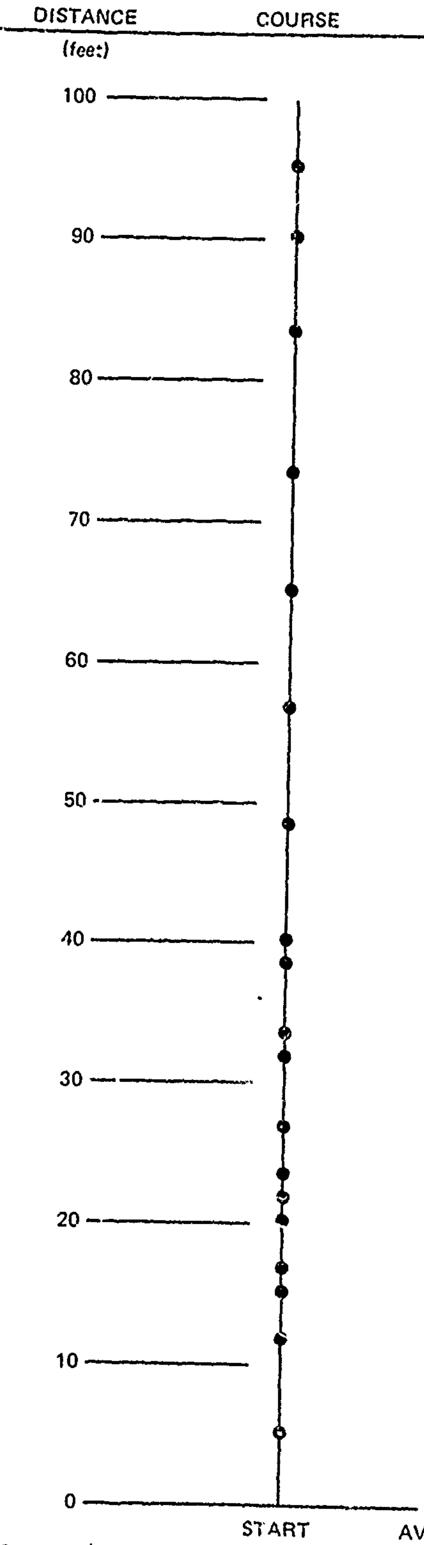


Figure 27. Force Required to Fail and Override a Tree with M36A2, 5/2-Ton Truck (from General Equation).



TYPE VEGETATION	INDIVIDUALLY MEASURED STEM DIAMETER (inches)	COMPUTED* EFFECTIVE STEM DIAMETER (inches)
2 Trees	1.4, 2.0	2.44
2 Vines	1.6, 1.2	2.00
2 Trees	1.1, 1.5	1.86
Tree	0.6	0.60
2 Trees	1.7, 1.7	2.40
3 Trees	1.0, 1.5, 0.9	2.01
Tree	2.5	2.50
2 Trees	0.5, 0.5	0.71
4 Vines	1.4, 0.8, 1.1, 1.1	2.24
Tree	0.4	0.40
3 Vines	0.9, 1.2, 0.7	1.66
Tree	2.1	2.10
Tree	1.1	1.10
Palm	6.0	6.00
Tree	1.7	1.70
Tree	0.5	0.50
Tree	0.75	
Palm	1.9	1.90
Tree	0.5	0.50
AVERAGE EFFECTIVE STEM DIAMETER		1.76

* When more than one tree was encountered by the vehicle at the same point along the course traversed, the effective stem diameter of the trees was considered to be a single tree having a stem cross-sectional area equal to the sum of the stem cross-sectional areas of the individual trees.

Figure 28. Typical Multiple-Tree Failure/Override Test Course

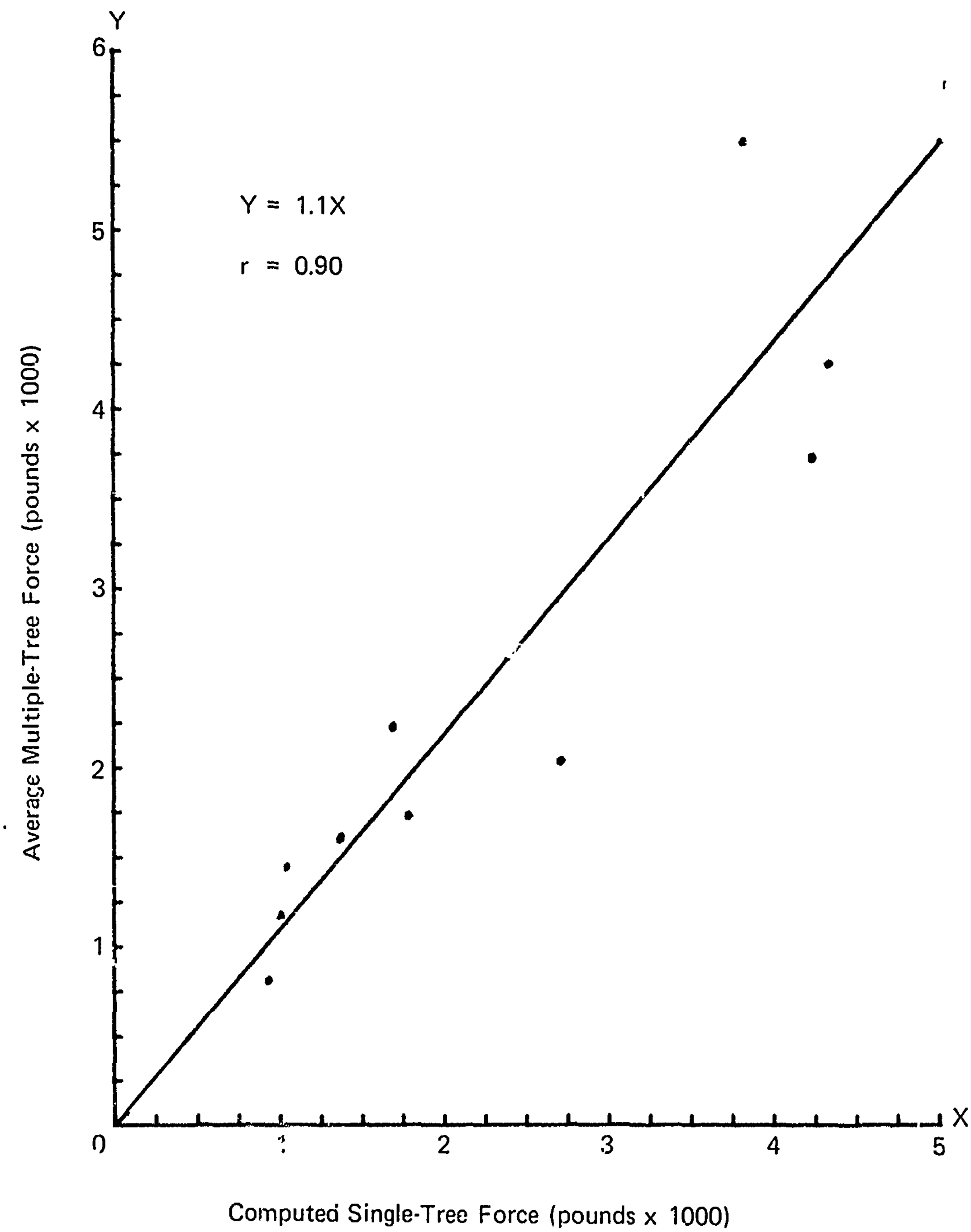


Figure 29. Single- versus Multiple-Tree Force Required to Fail and Override.

Grassland Penetration Tests

Results of this phase of testing are found in table D-3. Effects of tropic grass on the movement of vehicles off-road were determined by comparing the average force required to move through test lanes—first with the grasslands undisturbed and then with the grass crushed down by vehicular movement along the test lane. The results are summarized in the following tabulation.

Table 4. Summary of Grassland Penetration Test Results

Type of Vehicle	Average Force Required to Traverse Area with Standing Grass	Average Force Required to Traverse Area with Grass Removed	Increase in Force Due to Grass
	(pounds)	(pounds)	(percent)
M151A1, ¼-Ton Truck	420	390	7.7
M715, 5/4-Ton Truck	925	825	12.1
M36A2, 5/2-Ton Truck	1325	1112	19.2
All Vehicles	890	776	14.7

Tropic Grassland Maneuverability Tests

Details of the grassland maneuverability tests are given in table D-4 and are summarized below:

Table 5. Summary of Tropic Grassland Maneuverability Test Results

Type of Vehicle	Average Time Required to Traverse Test Course with Standing Grass	Average Time Required to Traverse Test Course with Grass Removed	Ratio of Time Required with and without Grass in Path
	(seconds)	(seconds)	
M151A1, ¼-Ton Truck	72.0	59.7	1.21
M715, 5/4-Ton Truck	32.3	25.7	1.26
M36A2, 5/2-Ton Truck	58.3	38.3	1.52
All Vehicles	54.2	41.2	1.32

Tropic Forest Maneuverability Tests

Results obtained for this phase of testing are in table D-5 and are shown graphically in figure 30. Figure 30 shows that the capability of a vehicle to maneuver through tropic forested areas falls off rapidly beyond approximately 100 feet, which is roughly equal to the outer limit of visibility through tropic vegetation.[22] This indicates that one of the primary limiting factors on the capability of vehicles may be the driver's inability to make decisions regarding changes in route selection once having entered the dense forest.

[22] *Jungle Vision VII: Seasonal Variations in Personnel Detectability in a Semideciduous Tropical Forest.*

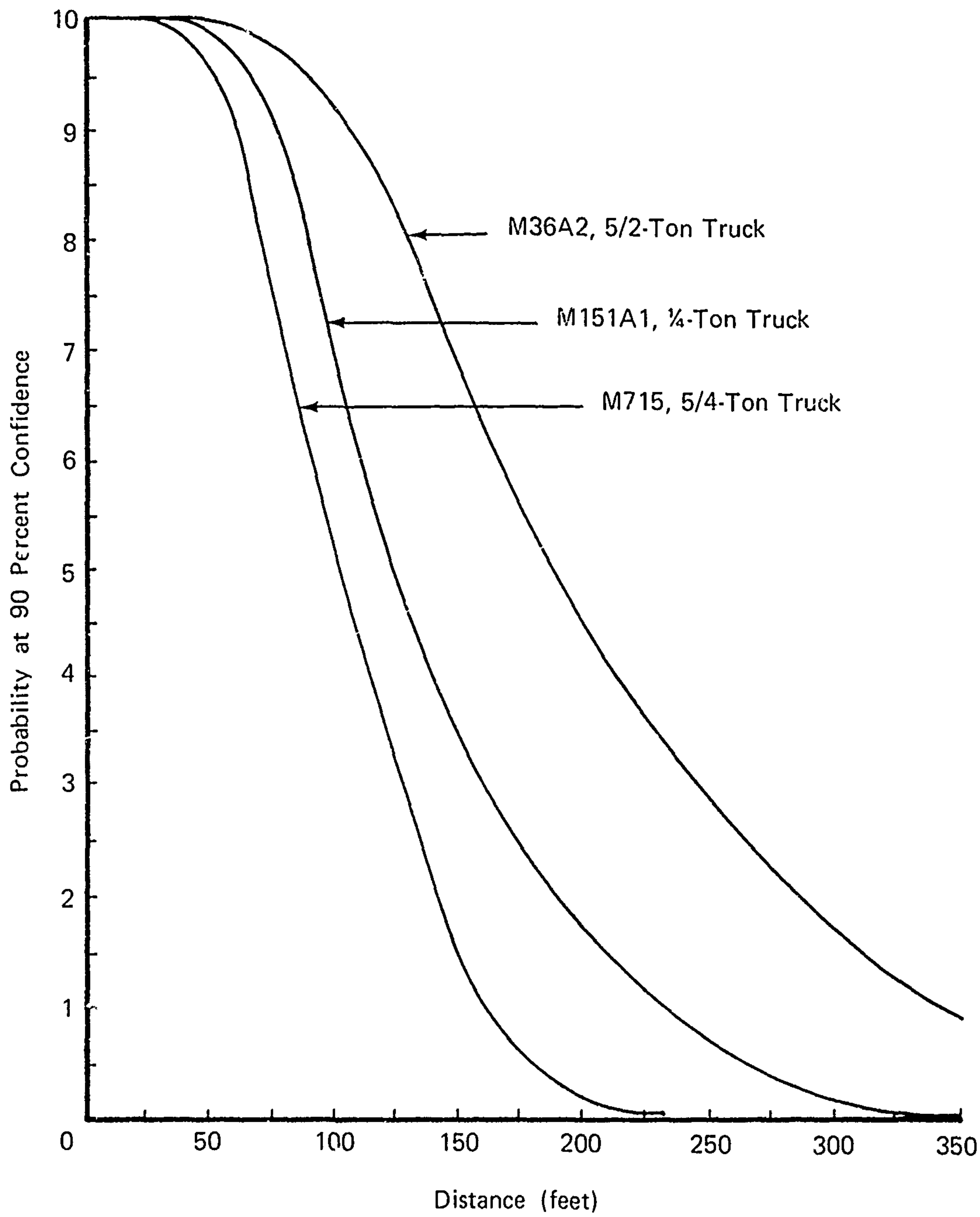


Figure 30. Tropic Forest Vehicular Penetration.

Another measure for determining the influence of tropic vegetation on maneuverability of vehicles is to compare the time required to transit a test course with and without vegetation along the path. This was accomplished for the tests reported herein with results summarized in the following tabulation.

Table 6. Summary of Tropic Forest Maneuverability Test Results

Type of Vehicle	Average Time Required to Traverse Test Course with Vegetation (seconds)	Average Time Required , Traverse Test Course with Vegetation Removed (seconds)	Ratio of Time Required with and without Vegetation in Path
M151A1, ¼-Ton Truck	55.0	21.8	2.52
M715, 5/4-Ton Truck	64.6	16.1	4.01
M36A2, 5/2-Ton Truck	48.4	26.2	1.85
All Vehicles	56.0	21.4	2.62

CONCLUSIONS

The following conclusions are offered:

- A single generalized equation can be used that accurately relates tree stem diameter to the force required to fail and override tropic trees using standard military wheeled vehicles.

- The force required to fail or override a single standing tree can be predicted from the stem diameter at breast height with 95 percent confidence.

- The force required to fail or override tropic trees in multiple arrays is approximately 1.1 times the force required to fail or override a single standing tree; this force can be predicted from the stem diameter at breast height.

- Tropic grasslands affect the movement of vehicles cross-country by requiring an average of 14.7 percent more force to override standing grass as opposed to movement through cleared areas, and increasing by an average of 1.30 the time required to traverse areas with standing grass as against time to traverse areas cleared of grass.

- The capability of standard military vehicles to traverse tropic forested areas is highly dependent on the visibility through such areas, i.e., drivers have difficulty selecting an alternate course once they have entered the forested area.

- Performance data compiled for the three military vehicles tested (M151A1, ¼-ton; M715, 5/4-ton; and M36A2, 5/2-ton trucks) offer sufficient guidance to plan future tests to evaluate the influence of tropic vegetation on vehicular mobility.

RECOMMENDATIONS

It is recommended that:

- The test methods set forth in this study be used in all future tropic mobility tests requiring vegetation override data.

- The results obtained in this study be used by TACOM for verification and refinement of the AMC '71 Mobility Model.

- The test procedures reported here and in an earlier USATTC mobility investigation, TECOM Project 9 CO 009 000 013,[16] be used to update MTPs 2-3-504[23] and 2-4-003,[24] or TOP 1-1-008.[25]

[23] MTP No. 2-3-504, *Cross-Country Mobility,* April 1970.
[24] MTP No. 2-4-003, *Wheeled, Tracked, and General Purpose Vehicles,* May 1971.
[25] TOP No. 1-1008, *Tropic Environmental Considerations,* March 1972.

SECTION II. APPENDICES

APPENDIX A. CORRESPONDENCE

DEPARTMENT OF THE ARMY
Headquarters, U. S. Army Test and Evaluation Command
Aberdeen Proving Ground, Maryland 21005

(COPY)

AMSTE-ME (22 Feb 73) 1st Ind Mr. Crowell/dg/870-2775
SUBJECT: Special Study, Mobility Description of Terrain

Headquarters, US Army Test and Evaluation Command, Aberdeen Proving Ground, Maryland 21005 9 Mar 1973

TO Commander, US Army Tank-Automotive Command, ATTN: AMSTA-RUR, Warren, Michigan 48090

1. Reference letter AMSTE-ME, 30 Aug 72, subject: Minutes of Mobility Meeting, 16 Aug 1972.

2. Reference letter with inclosure was furnished your headquarters on 30 Aug 1972. TACOM was represented at that meeting by Mr. Howard Dugoff of your office.

3. The purpose of the reference meeting was to initiate action for standardization of mobility testing throughout the TECOM complex and to determine a practical approach toward obtaining realism in such testing. Presentations were made by representatives from the Tropic Test Center, the Arctic Test Center, Yuma Proving Ground and the Armor and Engineer Board. With the exception of the Arctic Test Center, which agency has a unique weather related problem, the test agencies were developing terrain and/or test course definitions. The difference in procedures used at the agencies to accomplish these definitions was due to the varying technical capabilities available. Additionally, presentations by WES and AMSAA covered the AMC-71 ground mobility model and the activities of the Army Wheels Study Group.

4. At the conclusion of the meeting Mr. Dugoff stated that our mapping and test course improvement programs were producing information that would be valuable in obtaining our eventual goal and also contribute to improving the predictive capability of the AMC model. Mr. Dugoff further stated that the model, in spite of its many advantages, could not be substituted for actual field testing.

5. From the above it can be seen that our problems are not so much related to lack of knowledge of what has previously been accomplished in the field of mobility testing but what should be our best direction of effort when terrain and course definition has been completed. Some of the basic areas of required investigations as seen by this headquarters are:

a. Obtaining realism is natural environment testing to insure that test item experience near identical stresses as will be encountered in the field.

b. Insuring uniformity of testing and the development of the necessary course maintenance procedures.

c. Determining the causes for satisfactory vehicular performance at one test site and failure at another under similar terrain and climatic conditions.

d. Insuring that tests are neither too severe nor too benign resulting in over or under design of equipment.

e. Isolating environmentally induced problems from those resulting from quality assurance, maintenance or human behavior.

f. Defining the correct test media for natural environment vehicular tests. The question exists as to whether terrain and vegetation in an approximately original state is a more realistic than a media that has been subject to previous disturbance.

g. Correlating natural test site characteristics with area of probable combat.

h. Precise determination of the effects of snow characteristics (depth, density, crystal size, etc.) on vehicular performance.

6. Your offer of assistance is appreciated. Mr. Dugoff will be contacted after allowing time for this reply to be evaluated by your agency. Contact at this headquarters is Mr. A. W. Crowell, AMSTE-ME, Autovon 870-2775.

FOR THE COMMANDER:

/s/Sidney Wise
/t/SIDNEY WISE
Dir, Methodology Improvement

CF:
Cdr, USATTC, ATTN: STETC-AD
Cdr, YPG, ATTN: STEYP-MMI
Cdr, APG, ATTN: STEAP-MT
Cdr, USAATC, ATTN: STEAC-PL-MI
Cdr, AMSAA, ATTN: AMXSY-CM
Cdr, USACRREL, ATTN: Dr. Harrison
Pres, USARENBD, ATTN: STEBB-MO
Dir, WES, ATTN: WES-FS

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DEPARTMENT OF THE ARMY
Headquarters, U. S. Army Test and Evaluation Command
Aberdeen Proving Ground, Maryland 21005

AMSTE-ME 18 Jun 1973

SUBJECT: Test Directive, Mobility Testing in Natural Environments TECOM Project No. 9-CO-009-000-015

Commander
US Army Tropic Test Center
ATTN: STETC-PD-M
Drawer 942
Fort Clayton, CZ

1. References:

a. TECOM Regulation 70-12, dated 1 June 1973.

b. Letter, AMSTE-ME, 25 May 1973, subject: FY-74 Methodology Program.

c. Letter, AMSTE-ME, 20 September 1972, subject as above.

2. This letter and attached STE Form 1189 (Incl 1) constitute a test directive for continuation of the subject investigation under the TECOM Methodology Improvement Program 1U765702D625. During FY-74 only RDT&E funds are being provided.

3. The Methodology Investigation Proposal at Inclosure 2 and the additional guidance provided at Inclosure 3 are the bases for headquarters approval of the subject investigation. Any deviation from the approved scope, procedures, and authorized cost will require approval from this headquarters prior to execution.

4. Special Instructions:

a. All reporting will be in consonance with paragraph 9, reference 1a. The final report, when applicable, will be submitted to this headquarters by 15 June 1974.

b. Recommendations on new TOP's, or revisions to existing TOP's will be included as part of the recommendation section of the final report (para 9c, TECR 70-12). Final decision on the scope of the TOP effort will be made by this headquarters as part of the report approval process.

AMSTE-ME 18 Jun 1973

SUBJECT: Test Directive, Mobility Testing in Natural Environments TECOM Project No. 9-CO-009-000-015

c. The utilization of funds provided to support the subject investigation is governed by the rules of incremental funding.

FOR THE COMMANDER:

/s/Sidney Wise
/t/SIDNEY WISE
Dir, Methodology Improvement

3 Incl
as

(END COPY)

USATECOM TRMS TRANSCRIPT SHEET TEST SCHEDULING	RCS STETO-600	PAGE 1 OF 1

TO: CDR TTC
Attn STETC-PD-M

☐ CO, APG, ATTN STEAP-MD-D

FROM:

TRMS PROJECT NUMBER

DIR (3)	COMMODITY (4-5)	ITEM (6-8)	MODEL (9-11)	TEST (12-14)	TEST AGCY (15-16)
9	CA	999	999	015	L3

CARD TYPE (1-2)	(3-16)	(17-21)	CRITICAL EVENT NO (22-23)	YR - M - DA (24-29)	(30-77)	R A 78	A C 79
22	DUPE	BLK	52	740615	BLANK	1	2

CARD TYPE (1-2)	(3-16)	PLAN EVENT (17-18)	(19-21)	ORIG SCD YR - MO (22-25)	REV SCD YR - MO (26-29)	ACTUAL COMPL YR - MO - DA (30-35)	(36-77)	R A 78	A C 79	S C 80	TEST PLAN PHASE
31	DUPE	01	BLK				BLK				DOCUMENTS RECEIVED
31	DUPE	02	BLK				BLK				PLAN SUBMITTED
31	DUPE	03	BLK				BLK				PLAN APPROVED
31	DUPE	04	BLK				BLK				EXTERNAL APPROVAL RECEIVED

CARD TYPE (1-2)	(3-16)	TEST EVENT (17-18)	(19-21)	ORIG SCD YR - MO (22-25)	REV SCD YR - MO (26-29)	ACTUAL COMPL YR - MO - DA (30-35)	(36-77)	R A 78	A C 79	S C 80	TEST EXECUTION PHASE
31	DUPE	10	BLK				BLK				TEST ITEM RECEIVED
31	DUPE	20	BLK				BLK				TESTING INITIATED
31	DUPE	30	BLK		7311		BLK	1	2	U	INTERIM EVENT
31	DUPE	40	BLK		7405		BLK	1	2	U	TESTING COMPLETED
31	DUPE	5_	BLK		7406		BLK	1	2	U	REPORT SUBMITTED
31	DUPE	60	BLK		7407		BLK	1	2	U	TEST COMPLETED
31	DUPE	65	BLK		7408		BLK	2	2	U	RETIRE TO HISTORICAL FILE

CARD TYPE (1-2)	(3-16)	CODE (17-18)	(19)	(20-21)	DATE SBM YR-MO-DA (22-27)	(28-31)	CE NO (32-33)	(34-37)	OLD CE DATE YR-MO-DA (38-43)	(44-47)	NEW CE DATE YR MO DA (48-53)	54	RESCHEDULE, SUSPENSION, OR CANCELLATION, DISCUSSION LINE 1 (55-71) LINES 2, 3, 4 (22-71)	(72-77)	R A 78	A C 79	S C 80
81	DUPE	R7	1	BLK	730613	CE	52	FR	730615	TO	740615	BLK	CONTINUATION	BLK	1	1	U
81	DUPE	DUPE	2	BLK	OF FY73 EFFORT									BLK	1	1	U
81	DUPE	DUPE	3	BLK										BLK			
81	DUPE	DUPE	4	BLK										BLK			

SUBMITTED BY (Signature & Date)	APPROVED (Signature & Date)
Horace M Witman 14 June 1973	Albert W. Crowell 14 Jun '73 J F Hall 15 Jun 73

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Updated 23 April 1973

1. TITLE: Mobility In Natural Environments--9 CO 009 000 015

2. INSTALLATION: U.S. Army Tropic Test Center
P.O. Drawer 942
Fort Clayton, Canal Zone

3. PRINCIPAL INVESTIGATOR Bill R. Davis
Analysis Branch
STETC-OO-A
Autovon 313-285-3318

4. BACKGROUND: This is a continuation of TECOM Project 9 CO 009 000 015, Mobility In Natural Environments, which was initiated in FY 72 and continued thru FY 73. To date the following items have been accomplished: (a) an evaluation had been made of existing state-of-the-art techniques for use in determining the mobility characteristics of materiel items and the following tests were recommended for use in tropic testing-one-pass VCI tests, maximum drawbar pull-soil strength tests, acceleration-deceleration tests, slope negotiation tests, maneuverability tests, motion resistance-soil strength tests, obstacle tests, and vegetation tests; (b) techniques for predicting vegetation density in the tropics were developed; and (c) approximately eighty percent of the 20,000 acres contained in presently assigned Tropic Test Center test areas have been mapped with respect to their topographic, soils, vegetation, hydrologic, and climatic characteristics. Portions of the results of these investigations have been published in two reports entitled "Environmental Mapping of Tropic Test Sites, Report I, A Comparison of Three Methods For Predicting Vegetation Density In the Humid Tropics" and "Environmental Mapping of Tropic Test Sites, Report II, Vehicular Response Investigations." In addition a TOP on techniques for determining tropic vegetation density characteristics has been written and is awaiting review and publication.

5. STATEMENT OF THE PROBLEM: Adequate guidelines do not exist at the interaction of military vehicles and tropic vegetation, i.e., the ability of a vehicle to override or maneuver thru the jungle. In addition the procedures developed under earlier phases of this program as outlined in paragraph 4(a) above have not been incorporated into a TOP for use by Test Officers.

6. GOAL:

a. The investigation will result in definitive guidelines for use by Test Officers in evaluating the performance capabilities of military vehicles in the tropics. Results of this investigation will be incorporated in MTP 2-4-003, "Tropical Environmental Test of Wheeled and Tracked Vehicles."

b. This investigation will provide environmental factor maps for use with aerial mosaics as guides for selection of appropriate test sites to meet Test Directive requirements.

c. The investigation will result in definitive descriptions of the physical characteristics of the major test areas under the control of the US Army Tropic Test

Center. Results of this investigation will be incorporated in TOP 1-1-008, "Tropic Environmental Considerations". Where feasible the environmental parameters will be characterized in a format compatible with the AMC Mobility Model.

7. DESCRIPTION OF INVESTIGATION:

In addition to those tasks discussed in paragraph 4 above, the following tasks will be accomplished: (a) Techniques for determining the influence of tropic vegetation on vehicular movement will be evaluated. Test sites will be selected that are representative of tropic forests, and field tests will be conducted to determine the vehicle/vegetation interactions. The vehicles ability to override and maneuver thru tropic vegetation will be evaluated. (b) Standardized mobility test courses will be established to facilitate future testing in the tropics. Selection of these courses will be made to reflect varying degrees of operational difficulty for vehicles.

8. JUSTIFICATION:

a. Association with Mission:

(1) TECOM is the only Army Command with a subordinate test unit for tropic materiel tests and a permanent research group in the tropics with the capability to conduct the investigations. Determining the effects or non-effects of the tropics on materiel items is the primary mission of these units, part of TTC.

(2) Although other Army Installations and Commands have environmental missions (e.g., Waterways Experiment Station and US Army Natick Laboratories), past attempts to obtain nonreimbursable support for Tropic Test mission-oriented projects have met with little success. Army wide RDTE funding levels for tropic research programs offer little promise for future non-TECOM support.

b. Present capability, limitations, improvement, and impact of test if not approved:

(1) Present Capability:

In the past evaluation of vehicles in the tropics has been conducted for the most part on a "Go-No-Go" basis. In the early phases of this investigation, state-of-the-art techniques were evaluated and tests procedures selected for use by test officers in evaluation of vehicular performance capabilities in the tropics. The selected tests covers all phases of the environment that are considered significant from a mobility standpoint with the exception of vegetation. At the present time guidelines for evaluating the influence of vegetation on vehicular movement have not been firmly established.

(2) Limitations:

Evaluation of vehicle performance is limited at the present time to consideration of such factors as soil strength, slope characteristics, and natural obstacles. The effects of vegetation, which is probably the most significant tropic environmental parameter in terms of restricting vehicular movement, cannot be evaluated.

(3) Improvement:

Standardization of instrumentation and testing techniques for cross-country mobility in a tropic environment will be accomplished. It will then be possible to compare vehicle performance sequentially and on test courses of similar difficulty.

(4) Impact:

(a) The primary effect of "failure to fund" is the loss of approximately an $152,000 investment during FY 72 and FY 73.

(b) The performance capabilities of newly developed vehicles cannot be adequately evaluated under existing guidelines available to test officers.

c. Dollar Savings:

Tangible dollar savings cannot be determined. The investigation is one more in a series directed toward the number one methodology problem at TTC—the means to more precisely interpret the tropic environment and predict its effects on mobility.

d. Workland:

Over the past six (6) years the U.S. Army Tropic Test Center has experienced 51 tests directly pertinent to this investigation. The number of tests are shown below by test type.

PI	ED	ST	SP	SS	CK	RE	CF	PA	ET	TOTAL
11	7	5	11	5	2	7	1	1	1	51

The anticipated future workload is 36 tests. Examples of items anticipated for testing are:

Item	FY 74	75	76	77	78
Armored Recon Scout			ST	ST	
Shelter System M51		ES			
Mine Dispensing Subsystem	ST				
TOW	SU	SU	SU	SU	SU
Sand Bags	PI				
Prefab Airfield Surfacing	ED	ED	ED		
Desert-Tropic Test, CTG 762mm	SU	SU	SU	SU	SU
Tank, Fabric, M263			IP	IP	
Improved Float Bridge	ST				

e. Association with Requirements Documents:

Requirements taken from specified requirements documents (SDR, QMD) are listed below.

(1) Small Development Requirement for a Tactical Infantry Load Carrier. "It will be capable of operating in the warm-wet intermediate climatic areas described in AR 70-38, as changed." "The engine must be capable of starting and the vehicle being moved within 30 seconds under required climatic conditions."

(2) Small Development Requirement for Army Aircraft Weapons Handling Vehicle, Multipurpose. "The vehicle shall be able to operate in all types of terrain and be deployable by airmobile and air transportation modes."

(3) Small Development Requirement for Remote Area Demolitionist's Equipment Kit. "Be capable of being employed and functioning properly and/or stored under field conditions in wet-warm, wet-dry, humid-hot coastal desert, hot-dry, intermediate hot-dry, intermediate cold and cold climatic categories defined in Chapter 2, AR 70-38."

(4) Qualitative Materiel Development for a Rapid Soil Stabilization System. Section II. "2. It will rapidly and substantially increase the trafficability of soil to support foot troops, animals, vehicles, and aircraft in any land area under varied environmental conditions."

f. Others: Not applicable.

9. RESOURCES:

a. Financial

		Dollars in Thousands FY 74	
		In-house	Out-of-house
Personnal Compensation			
Permanent full-time		15.4	
Part-time			
Travel		1.0	
Contractual support			
Consultants & other svcs			2.5
Materials & supplies		2.0	
Equipment			
G&A costs		35.9	
	Subtotals	54.3	2.5
	FY Totals	56.8	

b. Explanation of Cost Categories.

(1) Personnel Compensation. Not applicable.

(2) Travel. Not applicable.

(3) Contractual Support. Not applicable.

(4) This investigation will be closely coordinated with the Tank Automotive Command and the Corp of Engineers who are primarily responsible for development of the AMC Mobility Model. Personnel from these agencies will be consulted to insure compatibility with the overall AMC mobility program.

(5) Materials & Supplies. Not applicable

(6) Equipment. Not applicable

(7) G&A Costs are computed at the rate of $22.00 per direct labor manhours. This rate, provided by TTC Budget Office, includes overhead cost and host-tenant agreement support cost.

c. Obligation Plan.

	FQ	1	2	3	4	TOTAL
Obligation Rate (Thousands)		29.8	27.0			56.8

d. In-house Personnel.

(1)

	Number	Manhours FY 74 Required	Manhours FY 74 Available	Manhours Total Required
Physicist, GS-1310	1	300	300	300
Forester/Botanists, GS-0406	1	350	350	350
Hydrologist, GS-1315	1	350	350	350
Research Met, GS-1340	1	130	130	130
Phys Science Tech, GS-1311	1	500	500	500
Civ Engr Asst (51G20)	1	500	500	500
		2130	2130	2130

(2) Resolution of non-available personnel. Not applicable

10. INVESTIGATION SCHEDULE:

	FY 74 J	A	S	O	N	D
In-house	–	–	–	–	–	R
Contract	–	–	–	–		
Consultants	–	–	–	–		

11. ASSOCIATION WITH TOP PROGRAM:

a. Revisions–Results of this investigation will be incorporated in TOP 1-1-008, "Tropical Environmental Considerations" and MTP 2-4-003, "Tropical Environmental Test of Wheeled and Tracked Vehicles."

b. New TOPs–Two new Background TOPs will be published as a result of these investigations: (1) a TOP describing techniques for measuring the density of tropic vegetation and (2) a TOP describing the environmental characteristics of TTC tropic test areas.

/s/Robert F. Callahan
/t/ROBERT F. CALLAHAN
COL, Armor
Commanding

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Organization: US Army Tropic Test Center

Investigation: Mobility Testing in Natural Environments

TRMs No. 9 CO 009 000 015

Total Cost: $56.8K

Approved Cost (FY 74): $25.0K

Unfunded: $31.8K

Comments: This investigation should be completed during FY 74.

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APPENDIX D. DATA TABLES

Table D-1. Results of

Test Number	Test Site	Tree Type	Branching Height (inches)	Tree Height (inches)	Crown Diameter (inches)	Stem Diameter DBH (inches)	Stem Basal Diameter (inches)	Work Required To Fail Tree (lb-in)	Work Required To Override Tree (lb in)	Maximum Force To Fail Tree (pounds)
M151A1, 1/4-Ton Truck										
1	A	*Cochlospermum vitifolium*	544	652	96	5.5	8.1	358400	882000	5600
2	A	*Cordia alliodora*	428	564	137	5.1	7.1	288000	1058400	4800
3	A	*Sheelia zonensis*	324	480	276	4.6	6.7	375040	1023364	5860
4	C	*Inga marginata*	284	482	114	4.5	7.4	151800	347760	2300
5	A	*Cordia alliodora*	223	368	164	4.4	5.8	208800	473600	2900
6	C	*Cordia alliodora*	92	364	120	4.1	5 6	173400	532100	3400
7	C	*Hirtella americana*	202	516	101	4.1	5.4	363000	476280	4840
8	A	*Cordia alliodora*	288	468	--	4.0	4.5	336000	†	4000
9	C	*Apeiba tiborbou*	48	312	160	4.0	4.7	206080	552960	3680
10	A	*Cupania fulvida*	219	374	168	3 8	4.6	112640	633600	2560
11	A	*Miconia argentea*	134	360	228	3.6	4.9	136500	682500	3900
12	C	*Cordia alliodora*	166	300	71	3.5	4.5	126000	412380	2000
13	A	*Inga spuria*	102	299	176	3.3	4.6	117760	†	2560
14	C	*Psidium guajava*	204	372	91	3.3	4.5	134000	270480	2680
15	C	*Bombacopsis sessilis*	*	162	*	3.2	4.7	115200	†	1800
16	A	*Miconia argentea*	79	255	155	3 0	4 3	116560	†	1880
17	A	*Miconia argentea*	124	276	125	2.6	4.2	100800	†	2800
18	C	*Miconia angentea*	135	276	108	2.5	3 8	109440	264480	2280
19	C	*Xylopia frutescens*	200	300	103	2.5	3.4	56160	167280	1040
20	C	*Annona spragnei*	192	340	117	2.5	3.6	66000	224960	1500
21	C	*Cordia alliodora*	309	401	162	2.5	2.8	54060	229680	1020
22	C	*Annona spragnei*	204	252	56	2.4	3.2	96800	240340	1760
23	C	*Cordia alliodora*	130	237	72	2.4	3 5	36980	147440	860
24	A	*Zanthoxylum* sp	176	279	126	2.3	2.8	107800	267520	1540
25	C	*Ceiba pentandra*	160	258	54	2.3	2.8	67940	206400	1580
26	C	*Gustavia superba*	214	348	56	2.3	3.2	109200	319680	2100
27	C	*Apeiba tiborbou*	162	295	120	2.3	2.7	75040	143640	1120
28	C	*Inga marginata*	96	168	360	2.2	2.8	64480	67840	1040
29	C	*Miconia albicans*	110	252	84	2.1	2.8	46000	86860	920
30	C	*Guazuma ulmifolia*	120	288	82	2.1	2.8	77900	167960	1900
31	C	*Apeiba tiborbou*	132	362	72	2.0	2.5	34960	199080	760
32	C	*Quassia amara*	54	228	92	1.9	2.7	30420	94500	780
33	C	*Apeiba tiborbou*	98	288	54	1.8	2.2	87320	283960	1480
34	C	*Miconia argentea*	127	244	96	1.8	3.0	56400	198720	940
35	A	*Miconia argentea*	168	276	36	1.5	1.9	131200	310400	1600
36	C	*Miconia argentea*	136	228	48	1.5	2.5	79680	223200	1660
37	C	*Annona spragnei*	74	264	72	1.5	1.8	21600	140160	480

* Topless Tree

† No override test conducted for reasons noted in remarks column

Test Number	Test Site	Tree Type	Branching Height (inches)	Tree Height (inches)	Crown Diameter (inches)	Stem Diameter DBH (inches)	Stem Basal Diameter (inches)	Work Required To Fail Tree (lb-in)	Work Required To Override Tree (lb in)	Maximum Force To Fail Tree (pounds)
M715, 5/4-Ton Truck										
38	C	*Annona spragnei*	160	576	204	6.0	7 3	621920	2061840	6760
39	C	*Cecropia* sp	552	720	154	7.3	9.3	508800	†	8480
40	C	*Cochlospermum vitifolium*	234	492	246	6 5	9.3	526500	1895880	8100
41	A	*Zanthoxylum* sp	278	502	89	5.7	7.4	603880	1821600	9740
42	C	*Xylopia feutescens*	186	404	192	5.6	7.2	438000	997600	7300
43	C	*Cochlospermum vitifolium*	373	499	121	5.4	7.9	435600	1212400	6600
44	C	*Cochlospermum vitifolium*	357	544	156	5.4	7.7	408900	†	4700
45	A	*Astrocaryum standleyii*	182	353	168	5.3	5.5	603520	1122300	6560
46	C	*Annona spragnei*	233	492	132	5.3	6.2	355000	3005600	7100
47	C	*Byrsonima crassifolia*	134	483	180	5.2	6 3	356160	2169160	6360
48	C	*Cochlospermum vitifolium*	348	506	144	5.2	7.0	409200	†	6200
49	C	*Miconia argentea*	39	372	249	5.1	9.0	360360	826200	5460
50	C	*Xylopia feutescens*	220	389	228	5.1	6.8	289600	942300	7240
51	C	*Cecropia* sp	300	538	141	5.1	6.1	355000	30056	5500
52	C	*Cochlospermum vitifolium*	231	468	101	5.0	7.3	365200	847000	4400
53	C	*Cochlospermum vitifolium*	234	450	153	4.9	7.2	412800	503200	5160
54	C	*Cecropia* sp	300	480	156	4.7	5.2	198720	698640	3680
55	C	*Guazuma ulmifolia*	117	336	240	4.5	6.3	312480	1019280	5040
56	C	*Byrsonima crassifolia*	77	396	144	4.5	5.1	201600	1224960	4200
57	C	*Cordia alliodora*	292	452	69	4.5	6.0	199500	1358800	3500
58	C	*Cecropia* sp	307	417	84	4.5	5.0	288000	717600	4000
59	C	*Cochlospermum vitifolium*	196	456	108	4.3	6.7	282080	1047200	3440
60	C	*Cochlospermum vitifolium*	300	408	60	4.2	5.9	217000	1284400	3100
61	C	*Miconia argentea*	212	336	101	4.0	4.6	194400	†	2700

Single-Tree Failure and Override Tests

Maximum Force to Override Tree (pounds)	Failure Angle (degrees)	Mode of Failure	Average Cone Index: 0 to 6-in. Layer	Average Cone Index: 6 to 12-in Layer	Average Cone Index: 12- to 18-in. Layer	Soil Classification: 0 to 6-in. Layer	Soil Classification: 6- to 12 in Layer	Moisture Content: 0 to 6 in Layer	Moisture Content: 6 to 12 in Layer	Remarks
1500	72 6	Taproot Tension	225	285	300	MH	CH	51 8	36 8	
2100	71 6	Root Tension	170	220	230	MH	MH CH	51 1	58 0	
2460	72.6	Uproot	220	280	300	MH	MH CH	54 2	39 1	
840	73 1	Uproot	290	300	300	MH	MH	40 1	38 5	
1600	74.5	Root Failure	220	280	300	MH	MH CH	54 2	39 1	
1700	68 6	Root Tension	250	290	300	MH	MH	58 1	42 4	
1080	75 1	Root Failure	200	290	300	MH	[illegible]	45 2	43 9	
†	76 6	Uproot	260	300	300	MH	MH CH	42 1	40 4	Tree slid under truck during override test
2160	70 3	Root Tension	220	280	300	MH	MH	45 3	41 7	Tree slid under vehicle during override test
1920	65 6	Uproot and Root Tension	220	280	300	MH	MH CH	54 2	39 1	
2100	60 3	Root Tension	170	220	230	MH	MH CH	51 1	58 0	Tree failed at [illegible] angle of vehicle
1740	72 4	Elastic Compression	220	280	300	MH	MH	45 3	41 7	
†	66 5	Uproot	260	300	300	MH	MH CH	42 1	40 4	Tree slid under vehicle during override test
840	68 2	Root Failure	200	290	300	MH	MH	45 2	43 9	
†	72 6	Taproot Tension	200	290	300	MH	MH	45 2	43 9	Topless tree [illegible]
†	72 1	Uproot	260	300	300	MH	MH CH	42 1	40 4	Tree slid under vehicle during override test
†	60 9	Stem Tension	170	220	230	MH	MH CH	51 1	58 0	Soil bank obstacle prevented override test
1160	67 4	Root Tension	220	280	300	MH	MH	45 3	41 7	
680	69 7	Root Tension	250	290	300	MH	MH	58 1	42 4	
760	65 6	Uproot	250	290	300	MH	MH	58.1	42 4	
660	69.3	Stem Tension	200	290	300	MH	MH	45.2	43 9	
1220	70 0	Elastic Compression	220	280	300	MH	MH	45.3	41 7	
760	65.1	Stem Tension Shear	250	290	300	MH	MH	58 1	42 4	
1280	74.1	Root Tension	260	300	300	MH	MH CH	42 1	40 4	
960	65 1	Uproot	250	290	300	MH	MH	58.1	42 4	
1080	69 0	Elastic Failure	200	290	300	MH	MH	45.2	43 9	
630	73.4	Taproot Tension	290	300	300	MH	MH	40 1	38 5	
640	72 1	Uproot	290	300	300	MH	MH	40 1	38 5	
430	68 2	Elastic Stem	250	290	300	MH	MH	58.1	42 4	
680	64.0	Taproot Tension	250	290	300	MH	MH	58 1	42 4	
630	66 5	Uproot	290	300	300	MH	MH	40.1	38 5	
500	62.9	Elastic Failure	200	290	300	MH	MH	45 2	43 9	
1240	71.3	Stem Tension	220	280	300	MH	MH	45.3	41 7	
1080	71.6	Root Tension	250	290	300	MH	MH	58.1	42 4	
1600	76 3	Taproot Tension	225	285	300	MH	CH	51 8	36 8	
1240	67 4	Root Tension	220	280	300	MH	MH	45 3	41 7	
640	66.0	Elastic Stem*	250	290	300	MH	MH	58 1	42 4	
4260	75.4	Taproot Failure	250	270	300	MH	MH	55 0	46 8	
†	68.2	Uproot	250	290	300	MH	MH	58 1	42 4	Override incomplete due to rain
4440	69.7	Taproot Tension	250	270	300	MH	MH	55 0	46 8	
4140	68 8	Uproot	225	285	300	MH	CH	51 8	36 8	
2900	68.2	Root Tension and Uproot	250	290	300	MH	MH	58.1	42 4	
2800	70 0	Stem Tension	250	270	300	MH	MH	55 0	46 8	
†	74.6	Taproot Tension	250	270	300	MH	MH	55 0	46 8	Tree top broke off during failure test
4300	75.4	Uproot	260	300	300	MH	MH CH	42 1	40 4	
6800	64 4	Root Tension	250	290	300	MH	MH	58.1	42 4	
5080	66 8	Root Tension	250	270	300	MH	MH	55.0	46 8	
†	70.0	Stem Tension	250	270	300	MH	MH	55 0	46 8	Tree top broke off during failure test
2700	70.0	Taproot Tension	220	280	300	MH	MH	45 3	41 7	
2700	59.0	Stem Shear and Root Tension	250	290	300	MH	MH	58 1	42.4	
2440	67.9	Root Tension	250	270	300	MH	MH	55.0	46 8	
2200	73.9	Taproot Tension	250	270	300	MH	MH	55.0	46 8	
1360	73 3	Root Tension	250	270	300	MH	MH	55.0	46 8	
1640	66.0	Root Tension	220	280	300	MH	MH	45.3	41 7	
3720	68 8	Uproot	220	280	300	MH	MH	45.3	41 7	
3520	63.4	Root Tension	250	290	300	MH	MH	58.1	42 4	
3440	67 2	Root Tension	250	270	300	MH	MH	55.0	46 8	
2080	71.6	Uproot	250	270	300	MH	MH	55 0	46 8	
2800	73.7	Taproot Tension	220	280	300	MH	MH	45.3	41 7	
3800	71 1	Taproot Tension	250	270	300	MH	MH	55.0	46 8	
†	71 6	Uproot	250	290	300	MH	MH	58 1	42.4	Tree slid under vehicle during override test

Table D-1 (cont)

Test Number	Test Site	Tree Type	Branching Height (inches)	Tree Height (inches)	Crown Diameter (inches)	Stem Diameter DBH (inches)	Stem Basal Diameter (inches)	Work Required To Fail Tree (lb in)	Work Required To Override Tree (lb in)	Maximum Force To Fail Tree (pounds)
M715, 5/4-Ton Truck (cont)										
62	C	*Zanthozylum sp*	124	336	248	3.9	6.2	316500	694260	4220
63	C	*Cochlospermum vitifolium*	332	424	97	3.9	5 6	194300	1085280	2900
64	C	*Cordia alliodora*	144	326	60	3.8	5.0	266960	334080	2840
65	C	*Miconia argentea*	158	365	103	3.5	3 8	278400	†	2900
66	C	*Zanthozylum sp*	267	414	127	3 5	5.4	438000	†	5840
67	C	*Curatella americana*	178	288	101	3.4	4.2	277200	364080	4200
68	A	*Luchea seemannii*	158	363	57	3.3	5.2	349140	2187360	5060
69	C	*Vismia ferruginea*	31	308	144	3.1	5 2	232320	†	2420
70	C	*Miconia argentea*	150	300	155	3.0	3 8	175200	272400	2400
71	C	*Miconia argentea*	147	294	105	2.8	3 6	156600	321600	2900
72	C	*Protium asperum*	180	341	147	2.8	3.5	102080	493020	2320
73	C	*Miconia argentea*	144	288	120	2.6	4 2	140600	376640	1900
74	C	Moraceae*	285	429	120	2.6	3.2	179200	686200	2800
75	C	*Miconia argentea*	103	264	132	2.2	4.0	192960	403200	2680
76	C	*Annona spragnei*	132	300	120	2.1	2 8	279720	429400	3780

* Specimen not readily identified since tree sample was sterile at time of test.
† No override test conducted for reasons noted in remarks column.

Test Number	Test Site	Tree Type	Branching Height (inches)	Tree Height (inches)	Crown Diameter (inches)	Stem Diameter DBH (inches)	Stem Basal Diameter (inches)	Work Required To Fail Tree (lb in)	Work Required To Override Tree (lb in)	Maximum Force To Fail Tree (pounds)
M36A2, 5/2-Ton Truck										
77	C	*Inga spuria*	540	634	250	7.1	8.7	1557360	†	15120
78	C	*Calophyllum sp*	370	610	270	6.5	8 9	1108600	3587160	9640
79	C	*Annona [illegible]*	387	608	108	6.1	9.9	400000	1454160	8000
80	A	*Cordia alliodora*	444	580	103	6.1	6.9	703080	2522660	7560
81	C	*Cochlospermum vitifolium*	440	735	168	6.0	7.3	408720	2154960	5240
82	A	*Astro[illegible] [illegible]andleyii*	294	494	336	5.9	7.3	794640	3817760	12040
83	C	*Calophyllum sp*	115	456	235	5.7	7.3	474000	1623600	7900
84	C	*Apeiba tiborbou*	178	564	132	5.5	6.2	400400	†	5200
85	C	*Miconia argentea*	388	648	171	5.4	7.2	449400	1884280	6420
86	C	*Inga spuria*	317	540	329	5.4	7.8	811200	1506120	10400
87	C	*Inga spuria*	282	532	192	5.3	6.2	1242300	†	10100
88	A	*Inga spuria*	456	612	255	5.2	7.1	624000	2552520	8000
89	A	*Zanthoxylum belizensis*	198	549	216	5.1	6.5	766080	2157600	9120
90	A	*Inga spuria*	300	632	220	5.1	6.4	914480	3898800	9940
91	A	*Inga spuria*	336	461	139	5.0	5.3	415840	2929900	9040
92	C	*Miconia argentea*	324	552	261	4.9	6.4	528240	1587600	8520
93	A	*Luehea speciosa*	339	510	204	4.7	7.1	802240	1688720	8720
94	A	*Miconia argentea*	340	576	185	4.6	6.2	331760	1886400	6380
95	A	*Inga spuria*	348	510	252	4.6	5.8	712320	1291680	7420
96	A	Fabaceae*	84	462	192	4.5	5.8	1001520	2371400	9360
97	A	*Zanthoxylum panamense*	397	510	185	4.5	6.3	481980	2047320	5540
98	C	Unidentified*	364	509	72	4.5	7.0	724880	1571360	8840
99	C	*Miconia argentea*	192	393	200	4.3	6.4	341880	941760	5180
100	C	*Cochlospermum vitifolium*	258	530	144	4.3	6.1	529920	1830840	5760
101	A	*Zanthoxylum sp*	156	400	140	4.2	6.0	283200	851200	3540
102	A	Unidentified*	598	684	144	4.1	5.5	482160	1570480	4920
103	A	Fabaceae*	252	436	168	4.0	4.7	630000	1204840	6000
104	C	*Dalbergia retusa*	336	570	168	4.0	4.2	418140	1482960	6060
105	A	*Miconia argentea*	426	576	180	3.7	4.7	488880	3001200	5820
106	A	*Cochlospermum vitifolium*	239	411	132	3.5	5.1	211200	497420	2400
[illegible]	C	*Dalbergia retusa*	169	462	245	3.4	5.7	256000	1138280	4000
[illegible]	A	*Inga marginata*	69	336	256	3.4	4.7	205360	823140	3080
10[illegible]	A	*Miconia argentea*	104	372	129	3.4	5.2	187680	1382240	4080
110	C	*Inga spuria*	216	456	155	3.0	4.5	433640	1016120	5860
111	C	*Dalbergia retusa*	156	300	152	3.0	3 8	297920	716800	3920
112	A	*Brownea ariza*	159	364	123	2.9	4.1	182160	755200	2640
113	A	*Terminalia amazonia*	338	492	176	2.6	3.8	446000	1317120	4460
114	C	*Protium asperum*	213	384	144	2.5	3.0	247760	643720	3260
115	C	*Inga spuria*	27	360	24	2.4	3.1	214500	652700	3900

*Specimen not readily identified since tree sample was sterile at time of test.
† No override tests conducted for reasons noted in remarks column.

Maximum Force To Override Tree (pounds)	Failure Angle (degrees)	Mode of Failure	Average Cone Index: 0 to 6 in. Layer	Average Cone Index: 6- to 12-in Layer	Average Cone Index: 12 to 18-in. Layer	Soil Classification: 0 to 6-in. Layer	Soil Classification: 6- to 12-in. Layer	Moisture Content: 0- to 6-in. Layer	Moisture Content: 6- to 12-in. Layer	Remarks
2660	72.3	Root Tension	220	280	300	MH	MH	45.3	41 7	
3040	70 3	Taproot Tension	250	270	300	MH	MH	55.0	46.8	
1440	75.7	Uproot	250	290	300	MH	MH	58.1	42 4	
†	76.0	Root Tension	250	290	300	MH	MH	58.1	42.4	Tree top broke off during failure test
†	72.3	Uproot	250	290	300	MH	MH	58 1	42 4	Tree slid under vehicle during override test
1640	70.0	Taproot Tension	220	280	300	MH	MH	45.3	41 7	
7440	70.8	Taproot Tension	260	300	300	MH	MH-CH	42 1	40.4	
†	76.0	Root Tension	220	280	300	MH	MH	45 3	41.7	Ditc obstacle prevented override test
1200	71 8	Stem Tension	250	270	300	MH	MH	55.0	46 8	
1340	66.0	Taproot Tension	250	290	300	MH	MH	58.1	42.4	
1660	61.4	Stem Tension	240	300	300	MH	MH	62 8	39.9	
1760	72.0	Uproot	250	270	300	MH	MH	55.0	46.8	
1880	69.4	Uproot	240	300	300	MH	MH	62.8	39.9	
2100	71.6	Root Tension	220	280	300	MH	MH	45 3	41 7	
1900	72.0	Stem Tension	220	280	300	MH	MH	45.3	41.7	
†	71.7	Uproot	150	250	300	MH	MH	51.6	40.4	Tie rod bent during override tests
7160	73.5	Uproot	210	280	300	MH	MH	57 4	43.6	
2920	55.8	Uproot	290	300	300	MH	MH	40.1	38.5	
5180	69.9	Stem Tension	--	--	--	MH	MH-CH	--	--	Field notes on soils data lost
3280	66.4	Uproot	210	280	300	MH	MH	57.4	43.6	
8920	62.7	Uproot	170	250	270	MH	MH-CH	62 4	58.2	
4100	60.5	Taproot Tension	210	280	300	MH	MH	57 4	43.6	
†	66.2	Uproot	240	300	30	MH	MH	62.8	39.9	Tree top broke off during failure test
3260	64.1	Uproot	240	300	300	MH	MH	62.8	39.9	
3260	66 4	Uproot	[illegible]	300	300	MH	MH	62.8	39.9	
†	74.5	Uproot	150	250	300	MH	MH	51.6	40 4	Tree top broke off during failure test.
4780	66.4	Uproot	220	250	290	MH	MH CH	55 8	48.5	
4640	68.0	Uproot	--	--	--	MH	MH-CH	--	--	Field notes on soils data lost.
7220	42.9	Uproot	--	--	--	MH	MH-CH	--	--	Field notes on soils data lost
7060	53.5	Stem Tension	220	250	290	MH	MH-CH	55 8	48.5	
3240	61.3	Uproot	290	300	300	MH	MH	40 1	38.5	
4040	69 7	Uproot	220	250	290	MH	MH-CH	55 8	48.5	
3600	56 8	Uproot	220	250	300	MH	MH-CH	55.8	48.5	
3120	70.5	Uproot	220	250	300	MH	MH-CH	55.8	48 5	
6680	72.4	Uproot	170	250	270	MH	MH CH	62.4	58.2	
4840	68.7	Uproot	220	250	300	MH	MH-CH	55.8	48.5	
3680	67.5	Uproot	240	300	300	MH	MH	62.8	39.9	
2880	62.7	Uproot	200	260	300	MH	MH	61.5	47.0	
4180	69.7	Stem Tension	200	260	300	MH	MH	61.5	47.0	
2660	67.0	Root Tension	220	250	290	MH	MH-CH	36.1	48.4	
2680	52.2	Uproot	220	250	290	MH	MH-CH	55.8	48.5	
3640	72.1	Uproot	170	250	270	MH	MH-CH	62.4	58.2	
2960	63.8	Stem Tension	240	300	300	MH	MH	62 8	39 9	
6100	68.0	Uproot	220	250	290	MH	MH-CH	55.8	48.5	
1540	68.9	Root Tension	--	--	--	MH	MH-CH	--	--	Field notes on soils data lost
2860	62.0	Uproot	290	300	300	MH	MH	40.1	38 5	
3060	63.1	Root Tension	220	250	290	MH	MH CH	55.8	48.5	
4240	53.5	Stem Tension	220	250	290	MH	MH-CH	55.8	48.5	
2660	65.3	Taproot Tension	240	300	300	MH	MH	62.8	39.9	
3200	65.9	Uproot	240	300	300	MH	MH	62.8	39.9	
2560	63.8	Stem Tension	220	250	290	MH	MH CH	36.1	48.4	
3360	71.2	Uproot	220	250	290	MH	MH-CH	55.8	48.5	
2090	65.9	Stem Tension	240	300	300	MH	MH	62.8	39.9	
2140	58.3	Stem Tension	240	300	300	MH	MH	62.8	39.9	

Table D-2. Results of Multiple-Tree Failure and Override Tests

Test Number	Type of Vehicle	Type/Quantity Vegetation Overriden along Test Course			Stem Diameter of Vegetation Failed/Overriden (inches)		Force Required To Fail/Override Vegetation along Test Course (pounds)		
		Trees	Palms	Vines	Average Effective	Maximum	Average	Maximum	Computed*
116	M151A1 ¼-ton truck	9	5	1	2.62	3.9	1731	2940	1785
117	M151A1 ¼-ton truck	20	2	9	1.76	6.0	1170	2600	1009
118	M151A1 ¼-ton truck	12	6	11	1.65	5.0	804	1200	931
119	M151A1 ¼-ton truck	19	3	18	1.80	2.9	1445	3600	1038
120	M715 5/4-ton truck	17	1	3	1.28	2.4	1609	2880	1362
121	M715 5/4-ton truck	36	1	1	1.75	5.8	2232	4560	1681
122	M715 5/4-ton truck	13	0	7	2.85	8.2	2044	3880	2711
123	M36A2 5/2-ton truck	11	3	6	2.60	5.2	5503	10,000	3811
124	M36A2 5/2-ton truck	17	1	9	2.92	7.1	3734	5500	4220
125	M36A2 5/2-ton truck	4	0	3	3.00	4.2	4257	5060	4326

* Computed from single-tree fail-and-override equations pertinent to each vehicle for comparison to average force in foregoing column.

Table D-3. Results of Grassland Penetration Tests

Test Number	Test Site	Type of Vehicle	Vegetation		Average Cone Index			Soil Classification		Moisture Content		Length of Test Lane	Average Force Required To Traverse Test Lane with Standing Grass	Average Force Required To Traverse Test Lane without Standing Grass
			Height	Density	0- to 6-in. Layer	6- to 12-in. Layer	12- to 18-in. Layer	0- to 6-in. Layer	6- to 12-in. Layer	0- to 6-in. Layer	6- to 12-in Layer			
			(inches)	(stems/m²)						(percent)	(percent)	(feet)	(pounds)	(pounds)
126	E	M151A1	94	146	220	280	300	MH	MH	45.6	44.3	32.8	300	300
127	E	M151A1	94	146	120	170	250	MH	MH	53.4	55.2	41.6	400	400
128	E	M151A1	94	146	120	170	250	MH	MH	53.4	55.2	45.5	600	500
129	E	M151A1	101	241	120	170	250	MH	MH	53.4	55.2	45.5	400	400
130	E	M151A1	101	241	120	170	250	MH	MH	53.4	55.2	48.6	400	350
131	E	M715	98	252	220	280	300	MH	MH	45.6	44.3	33.8	800	700
132	E	M715	98	252	220	280	300	MH	MH	45.6	44.3	49.7	900	700
133	E	M715	91	146	220	280	300	MH	MH	45.6	44.3	44.8	1000	1000
134	E	M715	87	146	220	280	300	MH	MH	45.6	44.3	40.5	1000	900
135	E	M36A2	93	100	300	300	300	MH	MH	56.9	41.5	33.6	1300	1200
136	E	M36A2	93	150	300	300	300	MH	MH	56.9	41.5	44.7	1400	1200
137	E	M36A2	93	150	300	300	300	MH	MH	56.9	41 5	43.1	1300	1100
138	E	M36A2	93	150	300	300	300	MH	MH	56.9	41.5	45.0	1300	950

Table D-4. Results of Grassland Maneuverability Tests

Test Number	Test Site	Type of Vehicle	Vegetation		Average Cone Index			Soil Classification		Moisture Content		Length of Test Lane	Reason for Stop	Travel Time		
			Height	Density	0- to 6-in. Layer	6- to 12-in. Layer	12- to 18-in. Layer	0- to 6-in. Layer	6- to 12-in. Layer	0- to 6-in. Layer	6- to 12-in. Layer			Time In with Vegetation in Path of Vehicle	Time Out with Vegetation Removed from Path of Vehicle	Time In ÷ Time Out
			(inches)	(stems/m²)						(percent)	(percent)	(feet)		(seconds)	(seconds)	
167	E	M151A1	77	37	280	300	300	MH	MH	57.0	41.2	209	End of course	79.8	62.2	1.28
168	E	M151A1	76	89	280	300	300	MH	MH	57 0	41.2	215	End of course	76.2	57.0	1.34
169	E	M151A1	78	64	280	300	300	MH	MH	57.0	41.2	203	End of course	60.0	59.8	1.00
170	E	M715	90	100	280	300	300	MH	MH	56.9	41 4	320	End of course	37.2	24.2	1.54
171	E	M715	81	73	280	300	300	MH	MH	56.9	41 4	320	End of course	33.4	28.2	1.18
172	E	M715	77	122	280	300	300	MH	MH	56.9	41 4	320	End of course	26.3	24 6	1.07
173	E	M36A2	78	98	280	300	300	MH	MH	56.2	41.0	269	End of course	58.9	46.8	1.26
174	E	M36A2	67	120	280	300	300	MH	MH	56.2	41.0	291	End of course	53.1	46.6	1.14
175	E	M36A2	68	106	280	300	300	MH	MH	56.2	41.0	307	End of course	62.9	21.4	2.94

Table D-5. Results of Tropic Forest Maneuverability Tests

Test No.	Test Site	Type of Vehicle	Distance Vehicle Traversed Prior to Permanent Stoppage (feet)	Reason for Permanent Stoppage of Vehicle	Characteristics of Vegetation that Resulted in Permanent Stoppage: No. of Trees and Vines	Diameters (inches)	Spacing (feet)	Minimum Distance between Trees Passed by Vehicle before Permanent Stoppage (feet)	No. of Times Driver Stopped or Backed Up to Maneuver around Obstacles before permanent Stoppage	Vehicular Travel Time: Time In with Vegetation in Path of Vehicle (seconds)	Time Out with Vegetation Removed from Path of Vehicle (seconds)	Time In ÷ Time Out
139	D	M151A1	223	Vehicle entangled with vines	Multiple	<1.0	Vehicle picked up at various points along travel path.	6.6	20	138.8	30.2	4.60
140	D	M151A1	98	Vines wrapped around wheels	Multiple	<1.0	Vehicle picked up at various points along travel path.	6.2	10	69.7	9.2	7.58
141	D	M151A1	101	Vehicle between two trees	2	(a) 5.7 (b) 5.3	12.8	8.2	7	52.2	13.4	3.90
142	D	M151A1	109	Log and three vines	4	(a) 6.2 (b) 1.4 (c) 1.1 (d) 1.1	Vines only (a) 2.2 (b) 2.4	7.5	0	24.2	15.5	1.56
143	D	M151A1	96	Three multi-stem trees	3	(a) 2.2 (b) 2.2 (c) 2.0 (d) 1.4 (e) 1.7	(a) 11.0 (b) 12.0	14.9	1	7.3	9.4	0.78
144	E	M151A1	161	End of course				6.3	3	84.4	21.2	4.00
145	E	M151A1	316	End of course				6.8	0	36.8	31.2	1.18
146	E	M151A1	203	Three trees	3	(a) 2.4 (b) 3.2 (c) 3.6	(a) 2.3 (b) 2.3	7.0	0	30.2	26.3	1.15
147	E	M151A1	114	Two trees	2	(a) 3.0 (b) 4.2	5.5	10.3	6	73.5	41.9	1.75
148	E	M151A1	171	End of course				8.1	0	33.4	19.9	1.68
149	D	M715	123	Four trees	4	(a) 5.0 (b) 9.2 (c) 5.0 (d) 7.1	(a) 8.6 (b) 8.0 (c) 5.0	10.3	14	146.5	9.2	15.92
150	D	M715	68	Two trees and three vines	5	(a) 2.2 (b) 2.2 (c) 2.3 (d) 1.7 (e) 3.5	(a) 12.0 (b) 2.3 (c) 1.5 (d) 1.0	8.4	12	80.6	13.5	5.97

151	D	M715	110	Hole in ground				16.2	0	38.6	9.6	4.02
152	D	M715	84	Four trees	4	(a) 8.0 (b) 2.1 (c) 4.2 (d) 4.3	(a) 11.7 (b) 4.0 (c) 5.0	12.5	0	27.3	8.0	3.41
153	D	M715	97	End of course				9.0	0	28.7	11.3	2.54
154	D	M715	121	End of course				10.3	5	64.5	20.0	3.23
155	E	M715	214	End of course				10.2	4	91.1	30.5	2.99
156	E	M715	176	End of course				9.1	0	33.2	27.0	1.45
157	E	M36A2	121	Five trees	5	(a) 5.2 (b) 4.0 (c) 3.4 (d) 3.4 (e) 2.0	(a) 10.0 (b) 6.0 (c) 7.8 (d) 6.2	12.0	0	41.7	19.4	2.15
158	E	M36A2	270	End of course.				11.2	0	73.9	54.0	1.37
159	E	M36A2	109	Four trees	4	(a) 3.3 (b) 9.8 (c) 4.7 (d) 4.2	(a) 10.2 (b) 16.3 (c) 7.8	10.5	0	32.0	21.9	1.46
160	E	M36A2	189	End of course				13.8	0	36.6	20.1	1.82
161	E	M36A2	138	End of course				13.5	0	50.0	24.2	2.07
162	E	M36A2	190	End of course				16.1	0	42.8	26.0	1.65
163	E	M36A2	208	End of course				11.1	0	48.4	28.6	1.69
164	E	M36A2	234	End of course				8.7	0	48.8	23.6	2.07
165	E	M36A2	179	End of course				12.8	0	50.3	28.4	1.77
166	E	M36A2	209	Gulley				12.9	2	59.0	16.1	3.66

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