AD-A121 604 MC4000 AUXILIARY MOVER(U) NAVAL SURFACE WEAPONS CENTER
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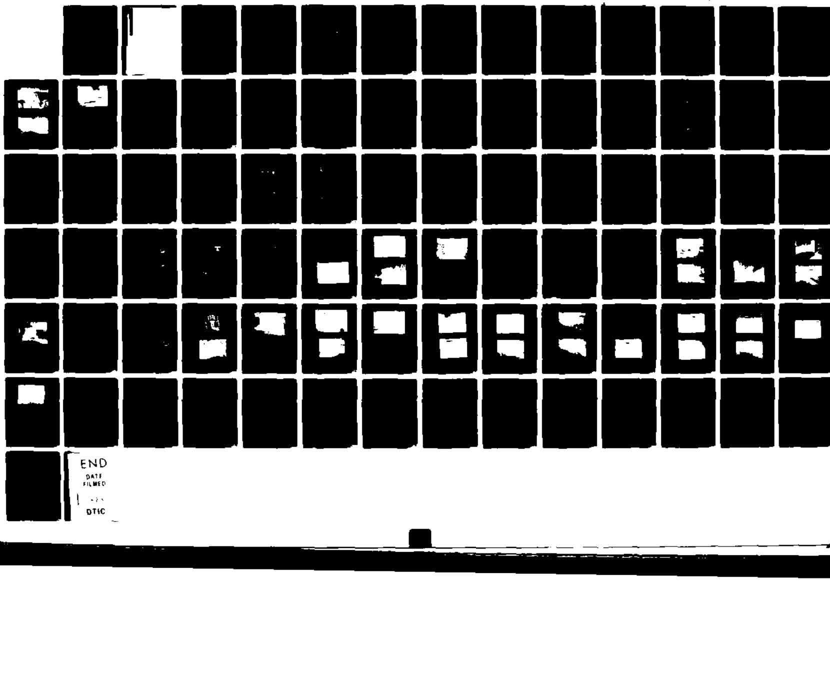

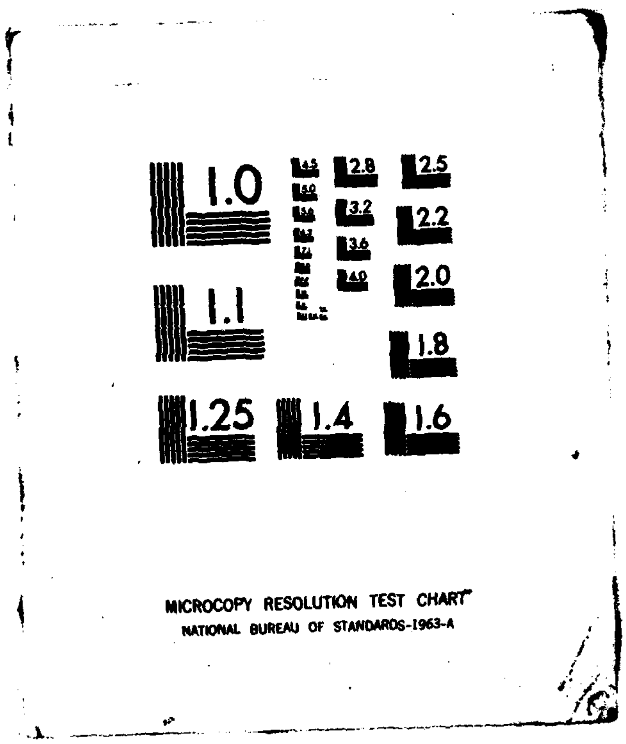
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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NSWC TR 81-454	2. GOVT ACCESSION NO. AD-A121604	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) MC4000 AUXILIARY MOVER		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Dan G. Haywood		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Surface Weapons Center (G31) Dahlgren, Virginia 22448		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62332N; F32300; ZF32300082
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Material Command Washington, D. C. 20360		12. REPORT DATE March 1982
		13. NUMBER OF PAGES 84
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Marine Corps Development and Education Command Quantico, Virginia 22134		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

rough terrain forklift (MC4000)
auxiliary mover
M198 towed howitzer

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

This report documents efforts to provide an improved local mobility for the M198 towed howitzer. The main efforts were directed to the design, fabrication, and testing of the items deemed necessary to provide the MC4000 rough terrain forklift with the capability to perform as an auxiliary mover for the M198 towed howitzer. Other efforts consisted of investigations of alternative functions for the enhanced MC4000 within and outside the artillery community.

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The performance of the enhanced MC4000 exceeded expectations and predictions. The MC4000 exceeded its requirements as an auxiliary mover for the M198 and excelled in handling other towed artillery, towed equipment, and functions outside the artillery community.

FOREWORD

This report describes the development of a suitable candidate to be used as an auxiliary mover for the M198 towed howitzer. These efforts were the direct result of the need for a solution to the transportability and mobility problems associated with the M198 towed howitzer.

The work was conducted as part of the Field Artillery Technology Program, Marine Corps Weaponry Exploratory Development of the Navy Strike Warfare Program Element 62332N.

This report was reviewed by J. S. O'Brasky, Task Manager, Field Artillery Technology, Weapons Development Branch; M. C. Shamblen, Head, Weapons Development Branch; and C. A. Cooper, Head, Gun Systems and Munitions Division.

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EXECUTIVE SUMMARY

The U.S. Marine Corps is in the process of replacing its M101A1 105-mm and M114A2 155-mm towed howitzers with the M198 155-mm towed howitzer. The size and weight of the M198 has caused severe local mobility problems, the most serious occurring during helicopter operations. After helicopter insertion into a landing zone without an auxiliary mover, the M198 is extremely difficult to maneuver. Currently, there is no satisfactory support vehicle capable of simultaneous helicopter operations with the M198 without the use of additional CH-53E sorties. The extreme length of the M198 combined with its prime mover (the M813 5-ton truck) severely restricts its maneuverability aboard amphibious ships and on helicopter flight decks.

OBJECTIVE

The program objective was to increase the combat efficiency of the direct support artillery battalion with improved local mobility for the M198 towed howitzer. It was apparent that this would require an auxiliary mover that would be

1. Helicopter transportable

2. Capable of moving the M198 for distances up to 1 km across marginal terrain and various soil conditions

3. Capable of maneuvering the M198 aboard amphibious ships

4. Capable of off- and on-loading the M198 aboard amphibious ships, landing craft, and transport aircraft

5. Available for the M198 initial operational capability (IOC)

APPROACH

The Marine Corps inventory of vehicles was examined for an auxiliary mover with the above capabilities, and the MC4000 forklift was identified as the prime candidate for a product improvement program (PIP) to fill this need. This rough-terrain, four-wheel-drive vehicle can lift 4000 lb, is air/ helicopter transportable, is towable, has fording capabilities, and has air-droppable features.

Prior to extensive design effort, it was decided to determine the ability of the MC4000, when linked with the M198, to negotiate various terrain and soil conditions. An experimental pintle hitch fabricated by the Naval Surface Weapons Center (NSWC) was fitted temporarily to an MC4000, and a feasibility demonstration was conducted at Fort Bragg, North Carolina in March 1979. The MC4000 demonstrated its capabilities as an auxiliary mover on flat broken ground under hard-packed to loose-sandy soil conditions.

As part of the PIP to equip the MC4000 as an auxiliary mover, a contract was let to the J. I. Case Company for the design, analysis, construction, and testing of proposed enhancements. The resultant PIP kit, which met all of the MC4000 requirements, contained

1. A pintle hitch that can be easily attached to one of the forks on either the MC4000 or M4K mast and is stowed on the side of the vehicle

2. An air brake control system for the air brakes on the M198

3. An auxiliary winch attached to the rear of the vehicle for self-extraction.

TEST RESULTS

The feasibility analysis predicted that the MC4000 would perform satisfactorily as an auxiliary mover for the M198 when enhanced with the PIP kit. Limited testing was conducted by the J. I. Case Company to certify completion of the design objectives; final interface and brake system performance evaluations were also conducted at this time. The results of these preliminary tests indicated that the PIP MC4000 would meet all design objectives.

Amphibious compatibility tests of the towed 155-mm M198 howitzer and the MC4000/M4K forklifts were conducted at the Naval Amphibious Base, Little Creek, Virginia. Test results indicated that the PIP MC4000 performed beyond expectations and predictions. Individually, the brake, winch, and hitch systems performed as expected, but the maneuvering capabilities of the MC4000/ M198 were much better than anticipated. The MC4000/M198 was able to maneuver over most terrain situations excluding dry soft sand. It demonstrated capabilities over the internal ramps, the stern gates, the flight decks, and the turntables of amphibious ships (LHA, LPD, LST, LSD) and through the port hatch of the LHA; it was also able to maneuver on the LCU and LCM-8 landing craft. The MC4000 and M198 can be crane lifted aboard all amphibious ships.

Additional field exercises conducted by the 10th Marines at Fort Bragg provided favorable results. During these exercises, the forklifts were used for approximately 80 percent of all material handling (ammunition, crates, trailers) and provided the majority of all trailer and generator maneuvering. The 10th Marine engineers were very enthusiastic with the ease with which the forklift handled the normally difficult and time-consuming loading procedures. The forklifts were returned with the 10th Marines to Camp Lejeune, South Carolina where they have operated successfully without major problems for approximately 180 hr.

CONCLUSIONS

The PIP MC4000 performed beyond the expectations and predictions of performance studies. The vehicles provided the minimum capability required to improve the local mobility of the M198 howitzer. These capabilities were convincingly demonstrated at Fort Bragg, Rock Island Arsenal, Camp Lejeune, and Little Creek.

In the auxiliary mover role, the MC4000 stows internally in a CH-53E helicopter as it sling lifted the M198 and ammunition for a total gun system insertion capability. The MC4000/M198 maneuvers from the landing zone over a variety of terrain up to a kilometer or more in the stowed or towed configuration.

The PIP MC4000 provides greatly improved mobility for the M198 howitzer aboard amphibious ships, landing craft, and transport aircraft. Even the most extreme ramp configurations are manageable. The LST turntable evolutions, ramp interfaces, and internal maneuverability problems of the M198 with its prime mover (the M813 5-ton truck) are greatly reduced or completely eliminated.

The auxiliary brake system performs as anticipated in the auxiliary mover role; the winch system functions very well and is readily used for self-extraction. The MC4000/M198 also proved itself in mounting-out evolutions including the handling of large towed generators. The PIP vehicle proved to be stable, controllable, and quite capable of achieving the required local mobility. Recommendations for several minor modifications to enhance the PIP vehicle (for reliability purposes rather than performance changes) are given in the Recommendations section.

INTRODUCTION

The U.S. Marine Corps is in the process of replacing its M101A1 105-mm (direct support weapon system) and M114A2 155-mm (general support weapon system) towed howitzers with the M198 155-mm towed howitzer. The adoption of this 15,600-lb, 40-ft-long, towed howitzer has created several local mobility deficiencies.

The most serious mobility deficiency occurs during helicopter operations. After helicopter insertion, the M198 becomes extremely difficult to maneuver over anything but the most favorable terrain without vehicular assistance. Currently, there is no satisfactory support vehicle capable of simultaneous helicopter operations with the M198 without the use of additional CH-53E sorties.

The extreme length of the M198 combined with its prime mover (the M813 5-ton truck) severely restricts its maneuverability aboard amphibious ships and on helicopter flight decks. The size, geometry, and weight of the M198 also creates on- and off-loading difficulties in transport aircraft.

OBJECTIVE

The program objective was to increase the combat efficiency of the direct support artillery battalion with improved local mobility for the M198 towed howitzer. It became apparent that completion of this task would require an auxiliary mover that would be

1. Helicopter transportable

2. Capable of moving the M198 for distances up to 1 km across marginal terrain and various soil conditions

3. Capable of maneuvering the M198 aboard amphibious ships

4. Capable of on- and off-loading the M198 aboard amphibious ships, landing craft, and transport aircraft

5. Available for M198 IOC

APPROACH

VEHICLE CHOICE

The initial step for this investigation was to examine the vehicles in the Marine Corps inventory. Although capability requirements and cost considerations narrowed the field quickly, the MC4000 rough-terrain forklift[1] was identified as the most reasonable potential candidate because it was already an active element in the artillery regiment.

The MC4000 is a rough-terrain, four-wheel-drive forklift with a 4000-lb capability; it is air/helicopter transportable, is towable, has air-droppable features, and has fording capabilities. The articulated frame steering of the MC4000 forklift, located at the center of the wheelbase, provides in-track turning. All heavy truck components are located in the rear frame, while the forklift mast and the operator's compartment make up the front module. The diesel-powered vehicle has a hydraulic full powershift transmission that contains internal wet disc service brakes.

PRELIMINARY WORK

Before extensive design efforts were initiated, it was decided to determine the ability of the MC4000, linked with the M198, to negotiate various terrain and soil conditions. This was accomplished with a feasibility demonstration at Fort Bragg in March 1979.[2]

The MC4000 was fitted with a temporary experimental pintle hitch (Figure 1). The MC4000/M198 demonstrated capabilities as an auxiliary mover over flat and flat broken ground under hard-packed to loose-sandy soil conditions (Figures 2 and 3). The MC4000 demonstrated considerably less interference than the M813 prime mover with the M198 howitzer in the stowed position. The MC4000 and M198 were stable, steerable, and controllable under all conditions. The test results from this demonstration are shown in Table 1.

Because the MC4000 forklift proved capable of providing a certain level of surface mobility for the M198 howitzer, a more detailed feasibility study of the MC4000 forklift auxiliary mover concept was recommended. A major design objective was to allow hookup between the MC4000 pintle and the M198 lunette in the stowed or towed configuration with the weapon trails on the ground. In addition, provision for an air brake system for the M198 and a winch system for self-extraction were to be incorporated on the MC4000.

CONTRACTOR PERFORMANCE

Requirements and desired capabilities were established as a result of the Fort Bragg demonstration. The J. I. Case Company was awarded a contract in September 1979 to investigate problems and provide detailed analysis, design, drawings, and tests for proposed solutions. The contractor responded to these

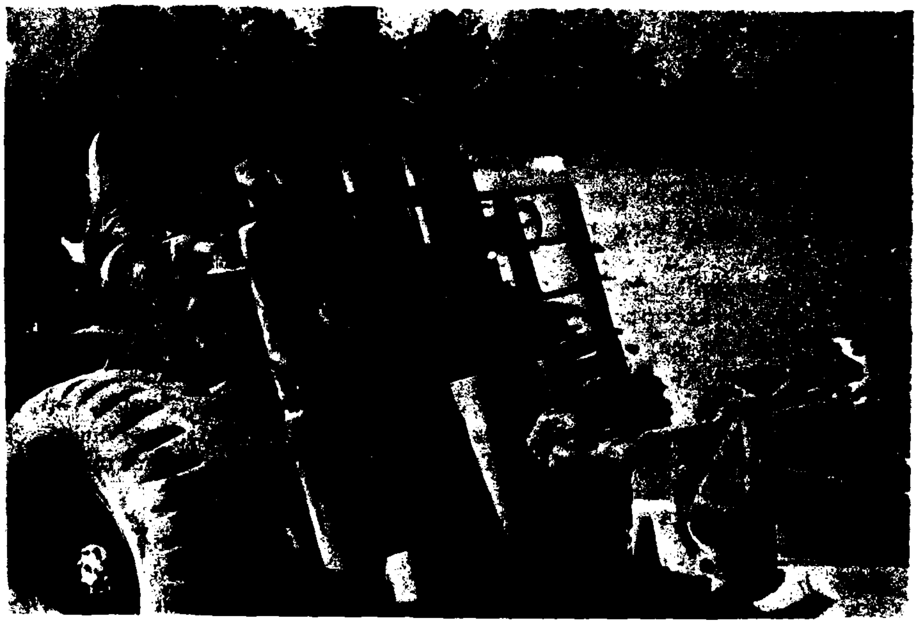

Figure 1. Fort Bragg Demonstration of MC4000 with NSWC Experimental Pintle Hitch

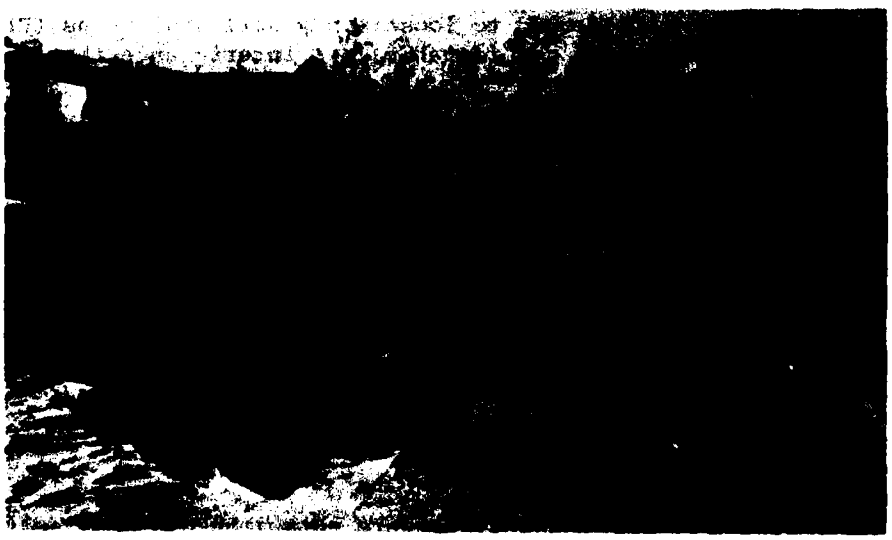

Figure 2. MC4000/M198 Towing in Stowed Condition Over Rolling Sandy Soil

Figure 3. MC4000/M198 Pushing in Towed Configuration Over Flat Sandy Soil

Table 1. Results of Feasibility Demonstration

Terrain	Vehicle Position: M198 Towed: One MC4000 Pulling	M198 Towed: Two MC4000s Pulling	M198 Towed: One MC4000 Pushing	M198 Stowed: One MC4000 Pulling	M198 Stowed: Two MC4000s Pulling	M198 Stowed: One MC4000 Pushing
Flat/flat broken (some loose sand)	F	--	F	F	--	F
Flat sandy	NF	NF	PWD	F/PWD	--	F
Incline hard-packed	--	--	--	F	--	--

Notes:
-- = not attempted
F = feasible
PWD = performed with difficulty
NF = not feasible

exigencies in a most rewarding manner. Reference 3 identified the major capabilities and expected limitations of the MC4000 as an auxiliary mover. The concept of using the MC4000 as the auxiliary mover for the M198 appeared valid and no major limitations were discovered.

Evaluation of the proposed PIP development for the MC4000 as an auxiliary mover indicated that the approach was sound but needed improvements. During this early conceptual development, it was discovered that the Marine Corps was considering increasing the MC4000 mast capabilities by using an Army version M4K mast. Since the J. I. Case Company produces the M4K mast and the vehicle modification had to be functional with the mast system selected by the Marine Corps, the contract was amended in January 1980 to include the fabrication and installation of an improved mast (M4K) on one of the two GFE (government-furnished equipment) MC4000s. A comparison of MC4000 forklift characteristics with the MC4000 and M4K masts is shown in Table 2.

Table 2. Comparison of MC4000 Forklift Characteristics with MC4000 and M4K Masts

Characteristics	MC4000 Mast	M4K Mast
Capacity at 24-in. load centers	4,000 lb	4,000 lb
Stage	Two-stage	Two-stage
Free lift	0	48 in.
Maximum lift height	68 in.	100 in.
Drop below grade	4 in.	4 in. est.
Side shift right & left	6 in.	22 in.
Rotation CCW & CW	10°	10°
Tine spacing	Manual	Manual
Mast tilt, forward	10°	10°
reverse	21°	20°
MILCON container compatible	no	yes
Overall length w/forks	198.5 in.	205.0 in. est.
w/o forks	158.5 in.	165.0 in. est.
Maximum height (top of ROPS)	85.7 in.	82.0 in.
Ground clearance	11.5 in.	10.0 in.
Wheel base	92.0 in.	92.0 in.
Tire tread	66.0 in.	66.0 in.
Width over tires	82.0 in.	82.0 in.
Weight	8,000 lb	9,800 lb est.

The proposed pintle hitch system required more welding and modification than desired. Along with the addition of the M4K mast, J. I. Case was requested to provide a pintle hitch that would be interchangeable with both units with as little vehicle and mast modification as possible.

Auxiliary mover design features to be included in the M4K mast were as follows:

1. The mast was to mount to the truck without modification of the truck structure.

2. Application of the M4K mast kit was not to reduce the basic performance of the truck as set forth in the MC4000 purchase description.

In addition, the M4K front-mounted pintle was to possess the capabilities to

1. Full-swivel with sufficient strength to tow and push the M198 howitzer

2. Be raised and lowered along the forklift mast

3. Be side-shifted

4. Be lowered sufficiently to engage the M198 howitzer lunette when the howitzer trails, without spades, are resting on a hard level surface

5. Be quickly stored by the forklift operator so as not to interfere with normal forklift operations

The contractor was to conduct a feasibility analysis to

1. Determine mast kit structural adequacy; the operational limitations in towing, pushing, and lifting; and tandem truck configurations with the M198 howitzer

2. Determine MC4000/M198 turning limitations with the M4K forklift mast kit

3. Evaluate performance variation of M4K/MC4000 caused by the change in total vehicle weight and weight distribution

4. Investigate interface compatibility with the M198, M114, M101, and M102 howitzers

The J. I. Case Company submitted an analysis[4] that included the further refinements and improvements requested for the PIP kit designs. A rather innovative hitch configuration that eliminated many of the problems of the earlier hitch designs was presented and adopted for PIP kit prototype hardware development.

By May 1980, one PIP MC4000 was ready for limited testing. A M198 at Rock Island Arsenal was used to conduct a preliminary interface and brake system functional evaluation. The brake system, structure, and interface adequacies were judged satisfactory for this limited maneuverability, braking, and ramp test. The evaluation certified that the design objectives had been met and that the vehicle would be adequate for field testing aboard amphibious ships, transport aircraft, and marginal terrain areas.

FIELD EXERCISES

In late July and early August of 1980, an amphibious compatibility test of the towed 155-mm M198 howitzer was conducted at the Naval Amphibious Base (NAB), Little Creek, Virginia. The prototype MC4000 and MC4000/M4K forklifts participated in the test as designated auxiliary movers. The prototype units proved very effective in their assigned tasks. Only one limitation was discovered. When trying to move across soft sand, the MC4000/M198 became bogged down in the sand, and the M198 had to be removed by a tracked vehicle.

After the successful demonstration at Little Creek, the prototype units were transported to the 10th Marines for field exercises. During the deployment, the vehicles were worked 90 to 120 hr each in a variety of roles other than M198 auxiliary mover. The units performed each assigned task in a highly satisfactory manner.

REQUIREMENTS AND OPERATIONAL CONDITIONS

The requirements and operational conditions stated earlier for the auxiliary mover were to be provided by the addition of

1. A front-mounted pintle
2. An auxiliary air system for activating the M198 brakes
3. A rear mounted winch

The criteria specified for these additional features on the MC4000 forklift were as follows:

1. The forklift must be able to act as an auxiliary mover for the M198 howitzer in both its towed and stowed configurations.

2. Changes to the MC4000 must not degrade its basic forklift capabilities and must have a minimum impact on its configuration/capabilities.

3. The front-mounted pintle should be designed with the capabilities to be

   a. Full-swiveled with sufficient strength to tow and push the M198 howitzer.

   b. Raised and lowered along the forklift mast.

   c. Side-shifted.

   d. Lowered sufficiently to engage the M198 lunette when the howitzer trails, without spades, are resting on a hard, level surface.

e. Quickly stored without disassembly by the forklift operator so as not to interfere with normal forklift operations.

4. The auxiliary air system should be capable of mating with and operating the M198 air brake system.

5. The rear-mounted winch should be designed so that

a. It provides the MC4000 with an improved lifting and pulling power.

b. The current rear-mounted towbar and pintle are retained.

FEASIBILITY ANALYSIS RESULTS

FEASIBILITY ANALYSIS, PART 1

The climbing of a hill requires that the prime mover have sufficient power available and that this power be transmitted to the ground to develop sufficient traction. These two limitations required separate analyses of the MC4000/M198 combination to determine the grades that it could negotiate. The results of these analyses were combined on curves and tables to determine the operational limitations of the combined vehicle.

Figure 4 shows the gradability of the MC4000/M198 combination by indicating the speed at which the combined vehicle can ascend a hill under various rolling resistances from 20 to 400 lb/1000 lb. This is the combined vehicle's performance, limited only by power output from the MC4000 diesel engine, and assumes that the wheels can develop the necessary traction. Figure 4 shows that the MC4000 provides adequate power for most roadbed conditions to be encountered. For relatively soft off-road conditions, where rolling resistance was 100 lb/1000 lb, the MC4000 provides sufficient power to climb grades in the 30 to 35 percent (17°-20°) range; for very soft conditions, 300 lb/1000 lb rolling resistance, it has enough power to climb 10 to 15 percent grades (6° to 9° slope).

A computer program was written to determine the steady-state force system of a four-wheel-drive tractor with a single-axle trailer on a slope. The program calculated the required coefficient of traction (traction factor or coefficient of friction) for the drive wheels of the four-wheel-drive vehicle pushing or pulling a trailer. Since only steady-state conditions were considered, only the forces required to hold the M198 on a slope, induce movement, or continue movement at a steady speed were determined; extra forces producing acceleration or deceleration were not considered.

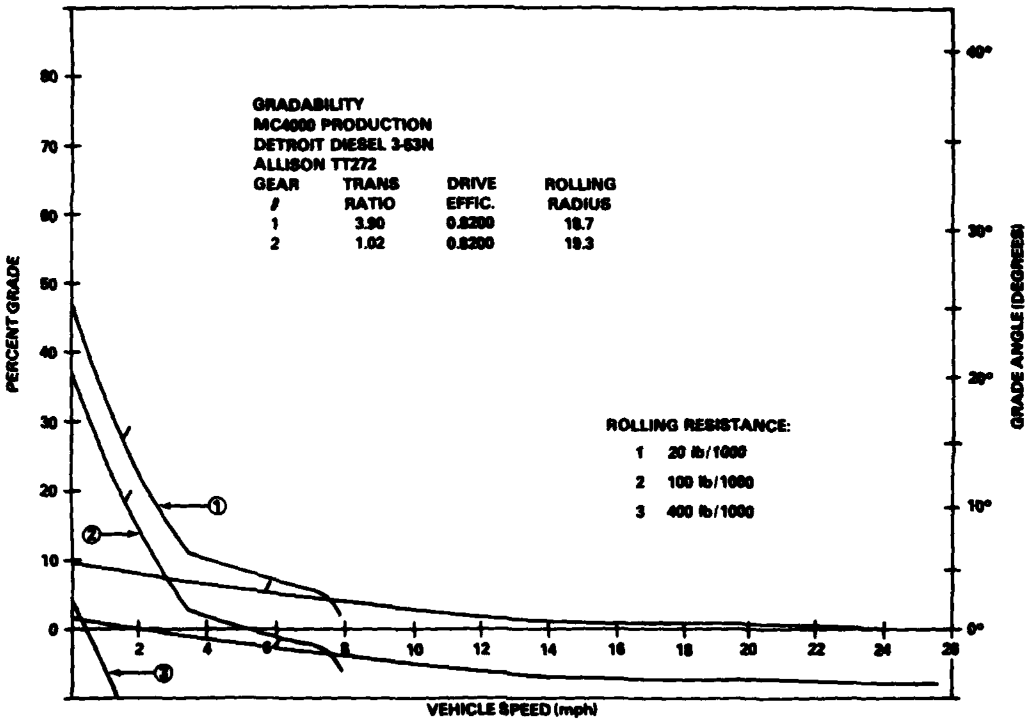

Figure 4. MC4000/M198 Gradability

Gradability

Stowed Configuration. The computer program was also used to calculate the forces acting on the MC4000/M198 vehicle on various grades. Figures 5 through 7 show the traction coefficients for the drive wheels of the MC4000 when pushing or pulling the stowed M198 howitzer up various grades or ramps with rolling resistances varying from 20 to 400 lb/1000 lb. The traction coefficients were plotted on Figures 5 through 7 along with the related horsepower limit at stall determined in the horsepower gradability study. These curves are only valid for ramps long enough to accommodate all three axles (32 ft) of the combined vehicle; if the ramp could accommodate only one or two axles, the required traction coefficient would be less. Although the curves show that the required traction factor is high (0.4 to 0.8) for steep hills (or long ramps), it is achievable under dry conditions. The MC4000 can also maneuver the stowed M198 up a shallow hill (2° to 3-1/2°) of fairly soft sand (300 to 400 lb/1000 lb rolling resistance) by reducing the tire pressure to obtain the 0.5 to 0.6 traction coefficient. For steep inclines, the MC4000 reaches a horsepower

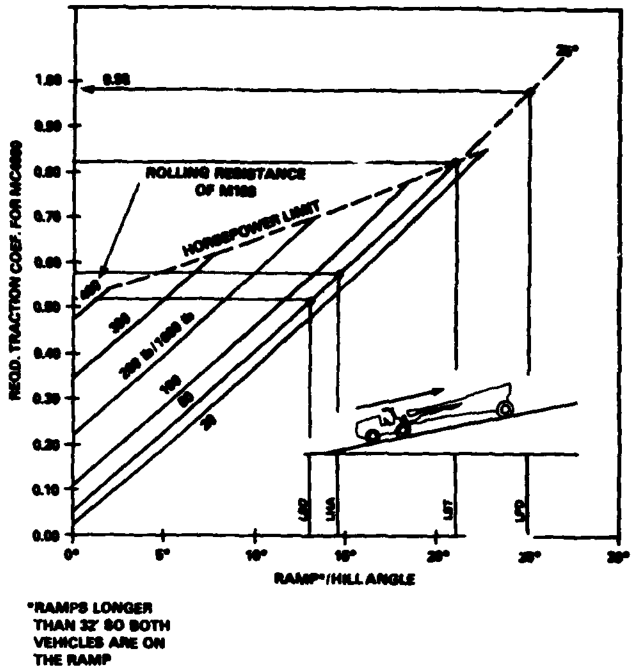

Figure 5. Traction Required for MC4000 to Push M198 (Stowed) Up Grades

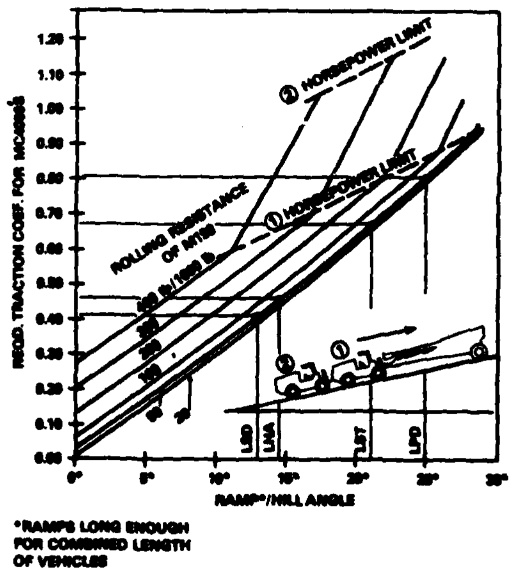

Figure 6. Traction Required for Two MC4000s to Push M198 (Stowed) Up Grades

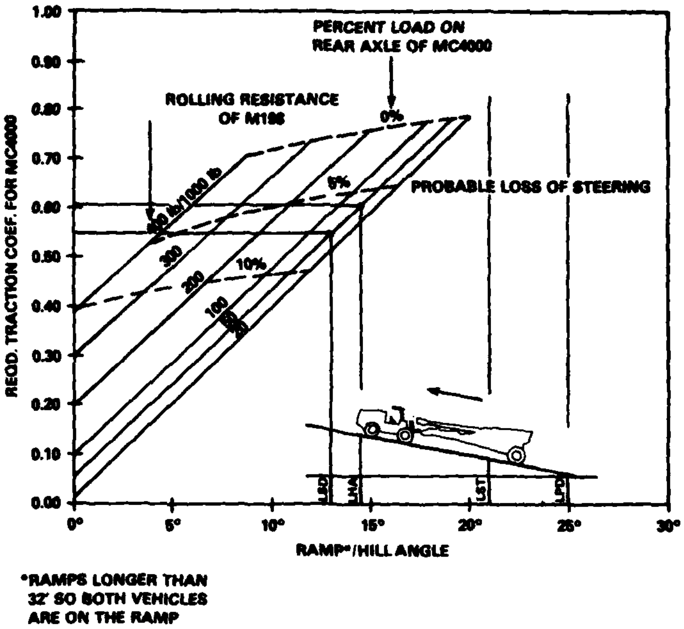

Figure 7. Traction Required for MC4000 to Pull M198 (Stowed) Up Grades

limit when traction is high (e.g., if the traction coefficient is 0.8 or greater, which is possible on a concrete surface, the MC4000 would be working at its horsepower limit on a long 21° ramp).

Traction coefficients required to pull a stowed M198 up an incline are given in Figure 7. For low rolling resistances (50 lb/1000 lb) there is little difference in the required traction coefficient whether pushing or pulling the M198 up an incline--0.52 for pushing and 0.55 for pulling up a 13° ramp. For the larger rolling resistances (300 to 400 lb/1000 lb), however, the load transfer from the howitzer to the forklift makes pulling advantageous--an 0.39 traction factor is required for pulling in a rolling resistance of 400 lb/1000 lb on a 0° slope compared with 0.47 for pushing.

This analysis does not consider actions that the operator might take to improve traction (i.e., articulating or walking the MC4000 so that only one wheel moves at a time or angling the drive wheels out of old ruts). This can be more easily accomplished when pushing the M198.

Towed Configuration. The gradability study results for the M198 in the towed configuration (Figures 8 and 9) are similar to those for the stowed configuration, although traction coefficients are higher because of the reduced load on the pintle of the forklift.

Once again, the power limit is theoretically reached for the MC4000--this time after the actual traction limit is reached--since the power limit line falls above the 1.0 traction coefficient line. If the off-road traction limit were 0.6 with a rolling resistance of 50, the MC4000 could push the towed M198 up a 10° hill, compared with a 16° hill for the stowed configuration.

The MC4000 probably could not move the towed M198 on level land with a high (300 to 400 lb/1000 lb) rolling resistance because it would lack a sufficiently high (over 0.6) traction coefficient. Although the required coefficient would reduce to 0.5 for level, very poor surfaces, the ability of the MC4000 to move the towed M198 is still questionable.

Pulling the towed M198 up a hill (Figure 9) is similar to pulling the stowed M198 up a hill (Figure 7) except that the required traction coefficients are somewhat higher. The 13°, 50-lb rolling resistance hill requires 0.74 traction for the towed version compared with 0.55 for the stowed version. In the towed configuration, the limit is almost always traction coefficient and not horsepower or weight on the rear axle. The curve shows that under most conditions (rolling resistance of 50 or less) the MC4000 should be able to pull the towed M198 up hills in the 10° to 15° range.

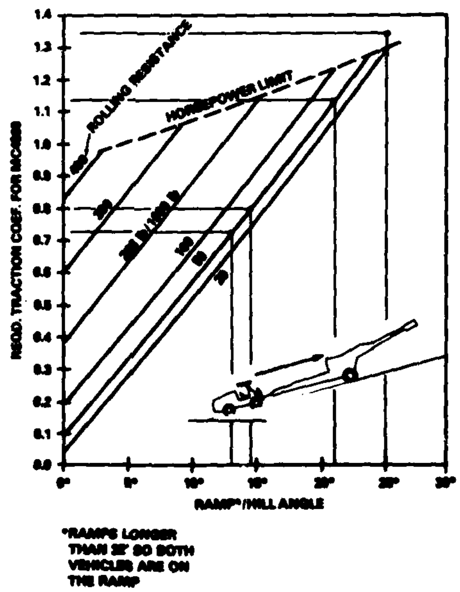

Figure 8. Traction Required for MC4000 to Push M198 (Towed) Up Grades)

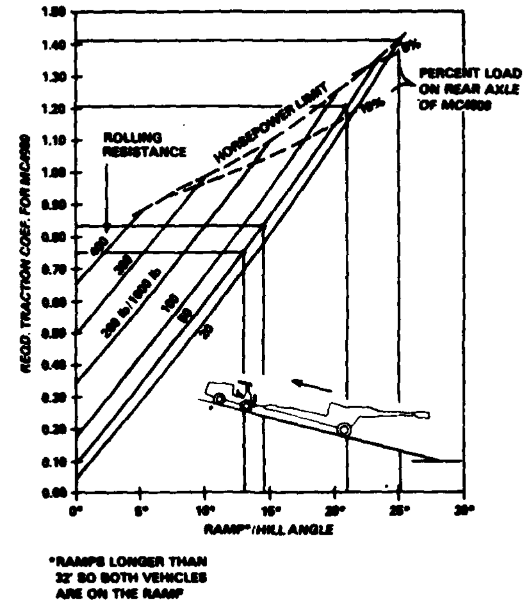

Figure 9. Traction Required for MC4000 to Pull M198 (Towed) Up Grades

Obstacle-Crossing Ability

Two types of obstacles--a ramp type and a round, log type--were studied to determine the limits for the MC4000 when pushing or pulling the M198. As in the gradability studies, limitations of horsepower, stability, and traction coefficient might prevent the vehicle from crossing an obstacle. The computer program was again used to determine the traction required for the forklift to push or pull the howitzer up a given ramp angle. An estimate was graphically made to relate a round cbject's diameter to an equivalent ramp angle.

Figure 10 depicts the path of the howitzer axles as the wheel moved over a round obstacle. At some point of engagement, the rate of lift or angle that the axles followed reaches a maximum then dropped to zero and down as the wheel passes over the obstacle. Figure 10 shows the two methods used to estimate this maximum angle: (1) the penetration of the obstacle into the wheel was assumed to range from two to two-and-one-half times the static deflection of the tire on flat ground and (2) the volume of the tire displacement by the obstacle was assumed to be the same as for the tire on a flat surface. The values for both methods of estimating lift angle show good agreement; they were plotted (Figure 11) and a curve was drawn through the points. The estimated maximum lift angle of the axle while going over a 7-in.-diameter log was 34°. This estimate was for creep speed, which neglects any momentum that would help carry the howitzer over the obstacle; therefore, it represents the worst condition where the greatest draw bar force and traction are required.

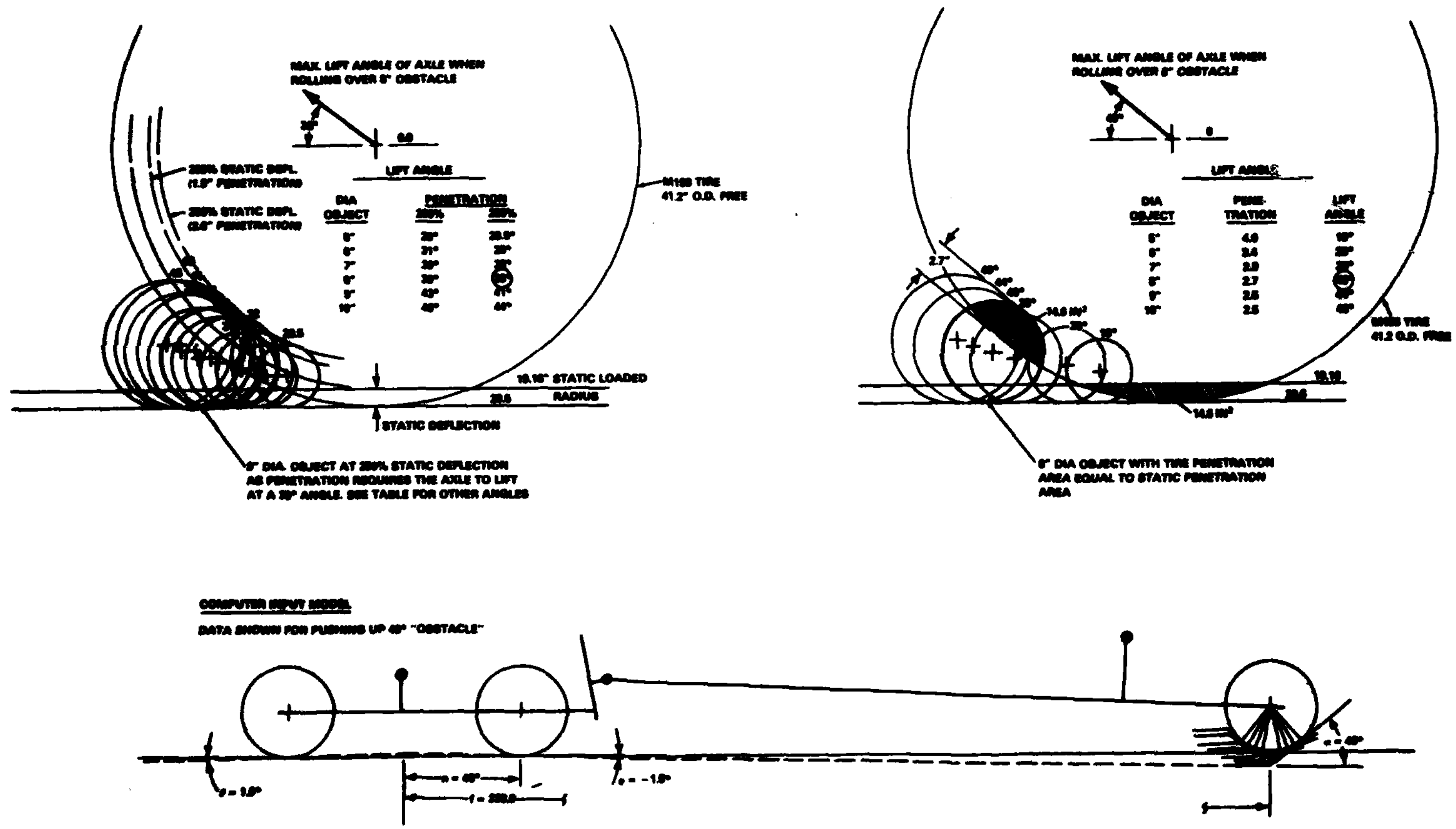

Figure 10. MC4000/M198 Obstacle-Crossing Analysis

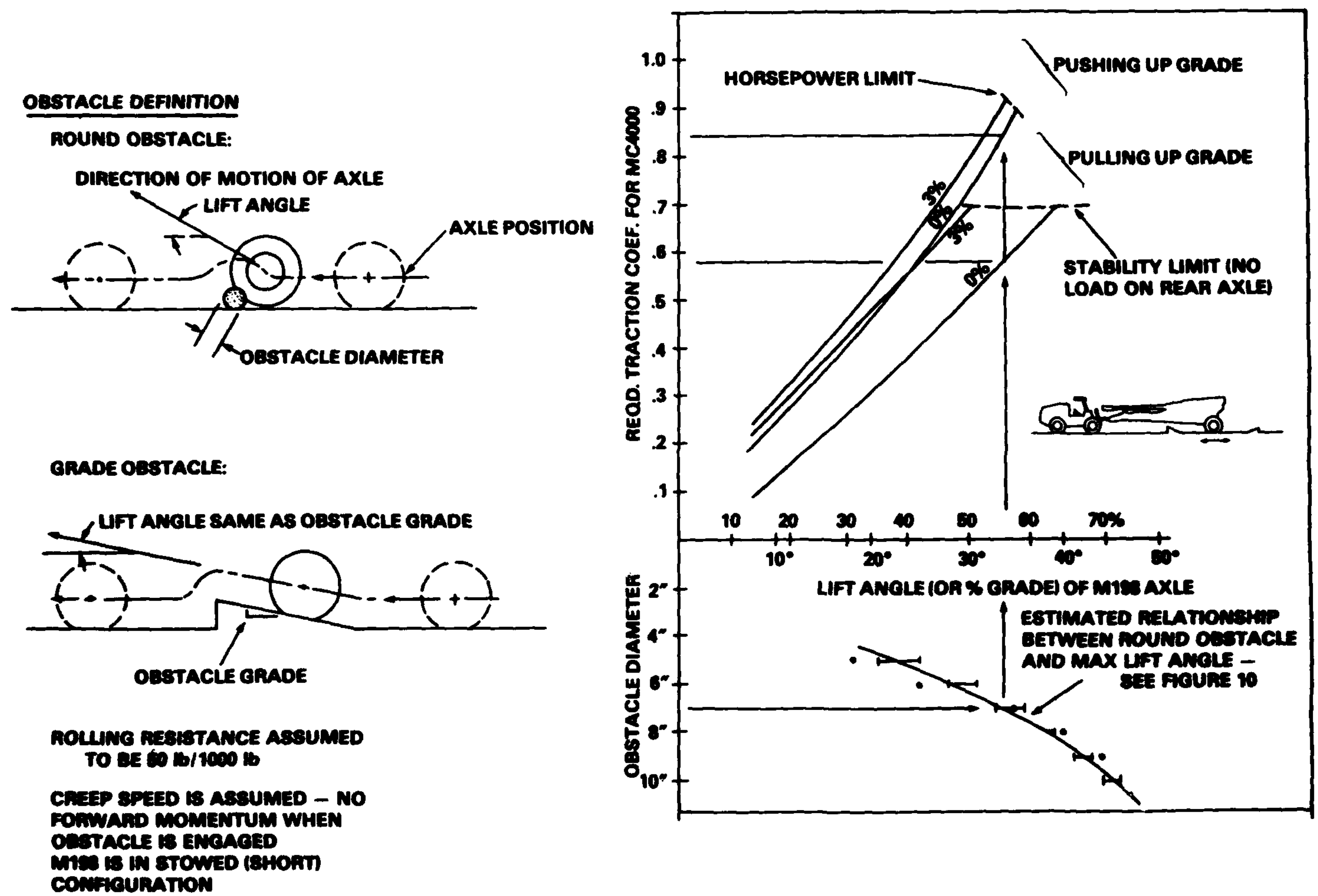

Figure 11. MC4000/M198 Obstacle-Crossing Curves

The computer program was again used to establish the traction coefficient required for various obstacle angles encountered by the M198 (stowed) wheels. Figure 10 shows how the grades were set up for each axle to simulate the vehicle encountering a small sloped obstacle. The obstacles were analyzed a second time, with a 1.72° angle added to the roadbed of each axle to simulate an obstacle encountered while pushing or pulling the howitzer up a 3 percent grade.

The line for the 7-in.-diameter obstacle mentioned earlier (34° lift angle) was extended onto the angle-vs-traction graph to determine the following required traction coefficients.

Howitzer	Roadbed Grade (%)	Required Traction Coefficient
Pushing	0	0.83
	3	0.91, but near horsepower limit
Pulling	0	0.58
	3	Forklift rear lifts up

Considering that this neglects the speed that would likely be built up before approaching the obstacle, this performance is reasonable. An operator should be able to achieve 3.4 mph on a 3-percent grade with fairly soft ground (100 lb/1000 lb rolling resistance) (Figure 4).

As pointed out in the Gradability section, the traction coefficient went to 0.58 when the howitzer wheels first encountered the 25° ramp. This same value is on the lift angle curve at 25° for pushing over an obstacle on a 0-percent grade. Therefore, these curves give the traction coefficients for short (up to 25 ft) ramps as well as obstacles.

Vehicle Stability

The traction coefficient curves show the limits of stability for the MC4000 while pushing or pulling a stowed or towed M198 howitzer. No stability problem exists when the forklift pushes the howitzer within all horsepower or traction limits. The only real stability limitation will probably be encountered if the MC4000 attempts to pull the M198 in its stowed condition up relatively steep ramps.

Proposed Front Pintle

Of the various pintle locations tried, that shown in Figure 12 appeared to best meet the stated objectives. Figures 13 through 15 depict the details of the proposed design. By holding the forks upward, side shifting the mast to the extreme left, and putting the pintle on the centerline of the machine, the left fork clears the muzzle brake.

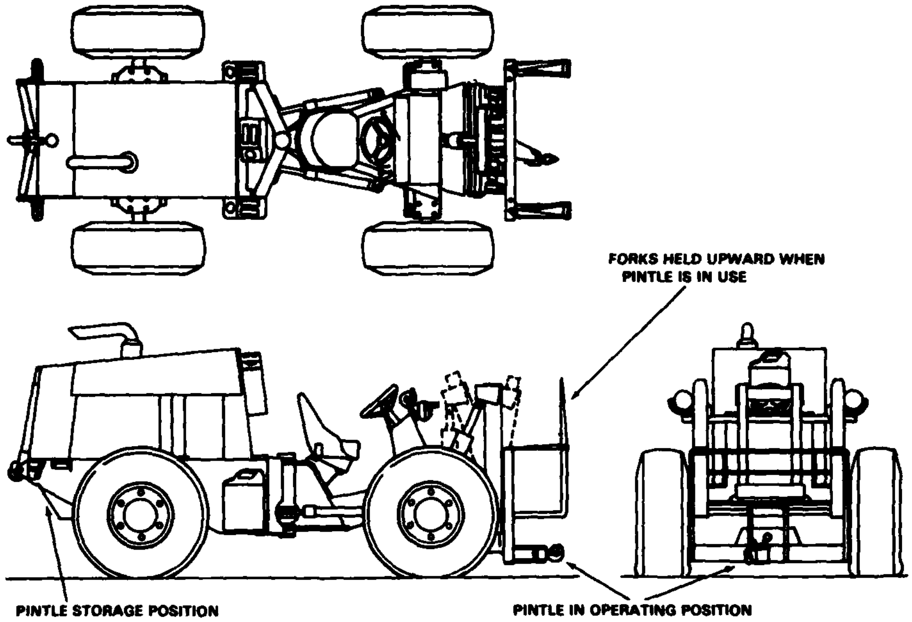

Figure 12. Initial Pintle Concept

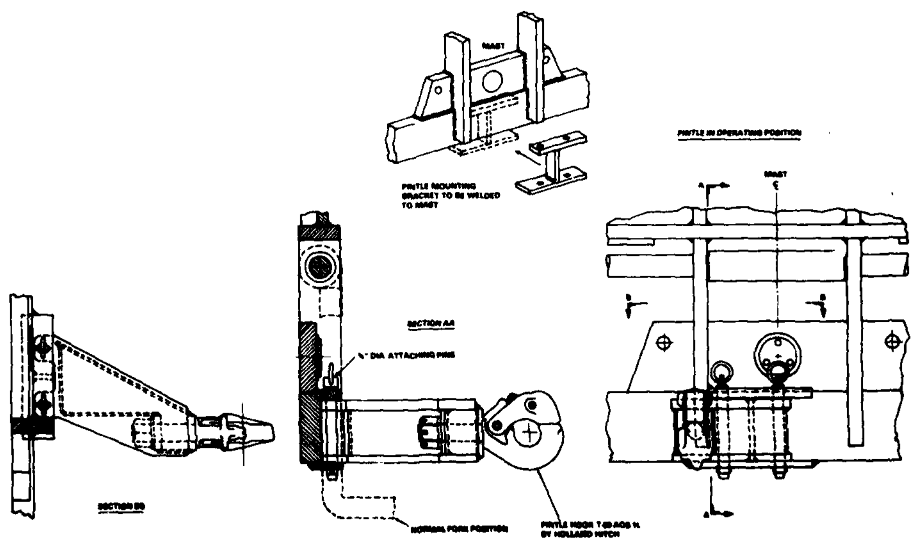

Figure 13. Initial Pintle Mount Concept Details

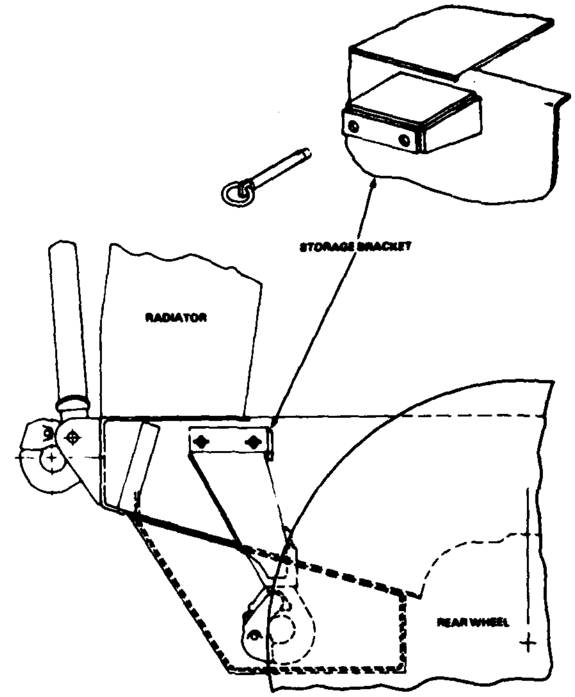

Figure 14. Original Pintle Stowage Concept

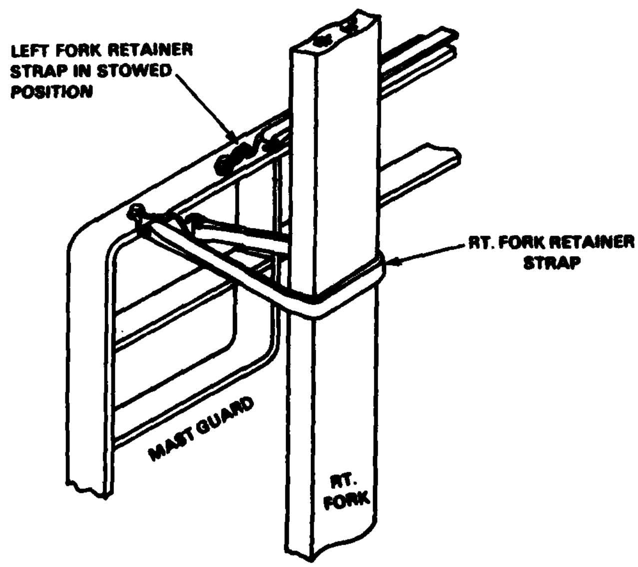

Figure 15. Fork Retainer Concept

Although the pintle could reach 2 in. below ground level to pick up the ho howitzer ring coupler, one restriction existed on the approach direction for pickup. The forklift could make its approach with the howitzer straight on or to the right without any problem. However, if the mast were tilted forward, the left fork would prevent an approach with the howitzer more than a few degrees to the left. Elimination of this restriction would probably require removal of the left fork during M198 (stowed) moving; this would not gain much in articulation angle when moving the howitzer.

Auxiliary Air Brake System

The auxiliary air brake system performance was based on the criteria found in SAE recommended practice J1152. The forklift/howitzer combination was considered as a tractor-scraper, defined as a vehicle with three axles, articulated steering, and front- and center-axle drive.*

The basic criteria for the brake system included the ability to

1. Hold the combination vehicle on a 25-percent grade

2. Stop the combination vehicle from a speed of 15 mph in 36 ft on dry swept concrete with the service brake (88 ft with the emergency brake)

3. Deliver, while stationary, at least 70 percent of the minimum required brake pressure when the brakes are fully applied 12 times at the rate of 4 applications/min

The locations of the major components of the proposed air brake control system are shown in Figure 16 and 17.

Auxiliary Winch

Figures 18 and 19 form a three-view layout of the proposed winch mounting on the rear of the MC4000 over the radiator. The cable is routed down from the winch spool and around a pulley mounted low on the rear of the chassis before going outward from the rear of the forklift. Thus, the winch is located where it is less likely to be damaged, but the pull on the forklift is low and on a structural member. The winch position requires that the exhaust pipe be relocated so that it points 30° from the previous straight rearward direction. Also, the cable routing requires that the stowed position for the rear towbar be relocated a few inches for clearance. This position for the winch, cable, and pulley appears to have no significant effect on the operation of the rear lights, pintle, or access for fueling; however, it will have some effect on access to the radiator fill cap and the operator's rear visibility.

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* SAE standard J1057a, line 5.1.3.

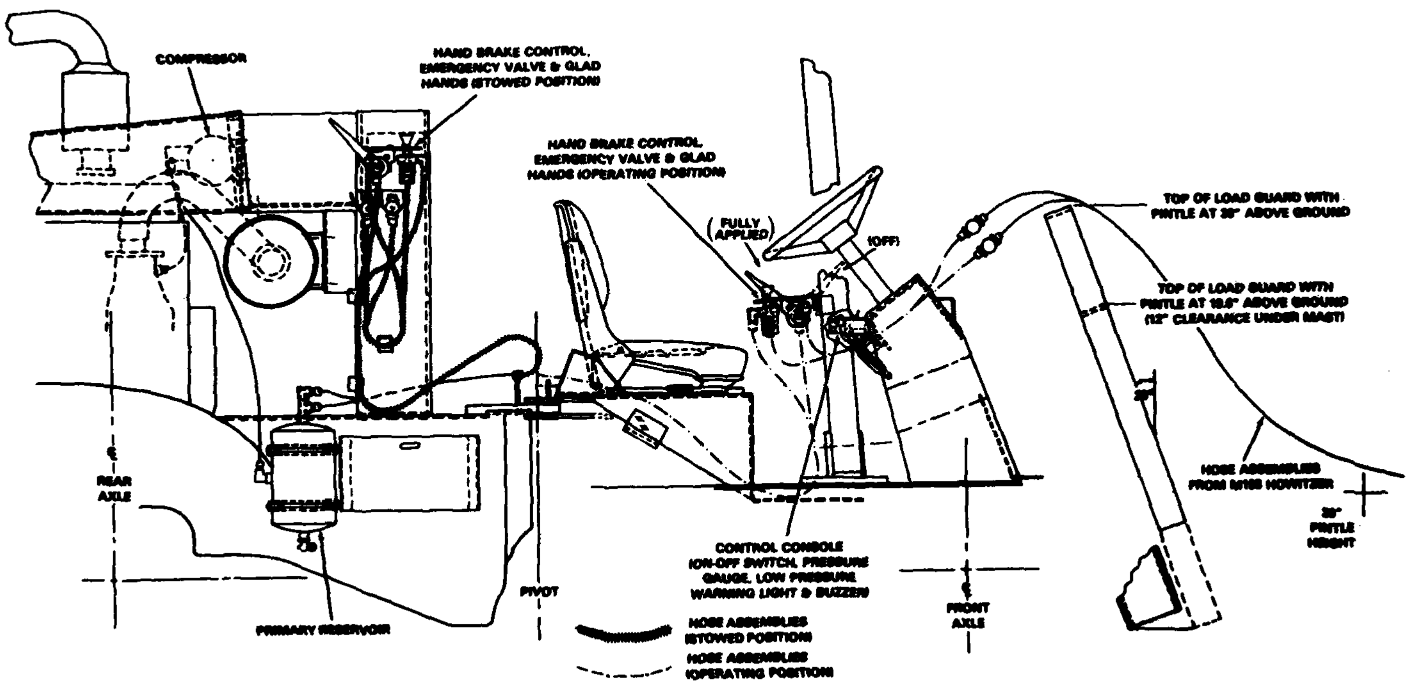

Figure 16. Air Brake System, Side View

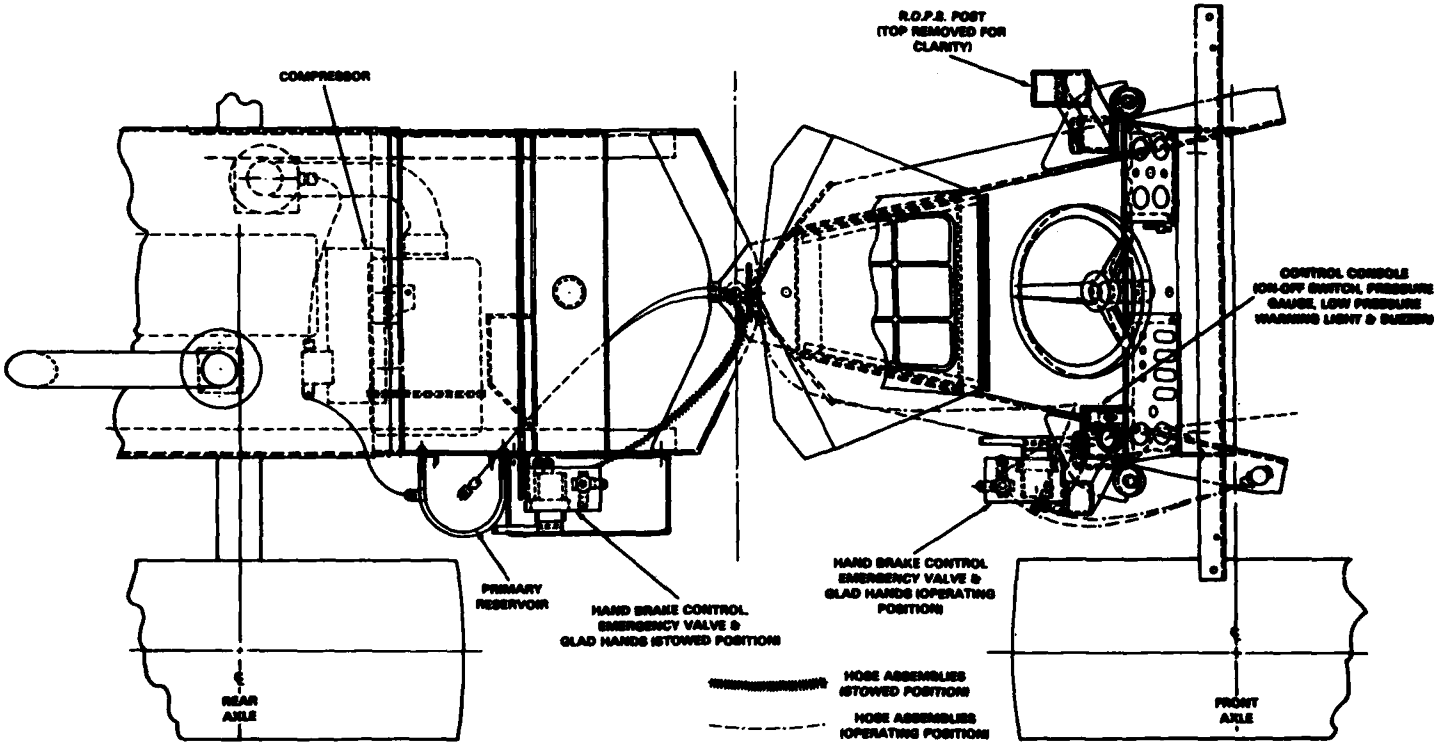

Figure 17. Air Brake System, Top View

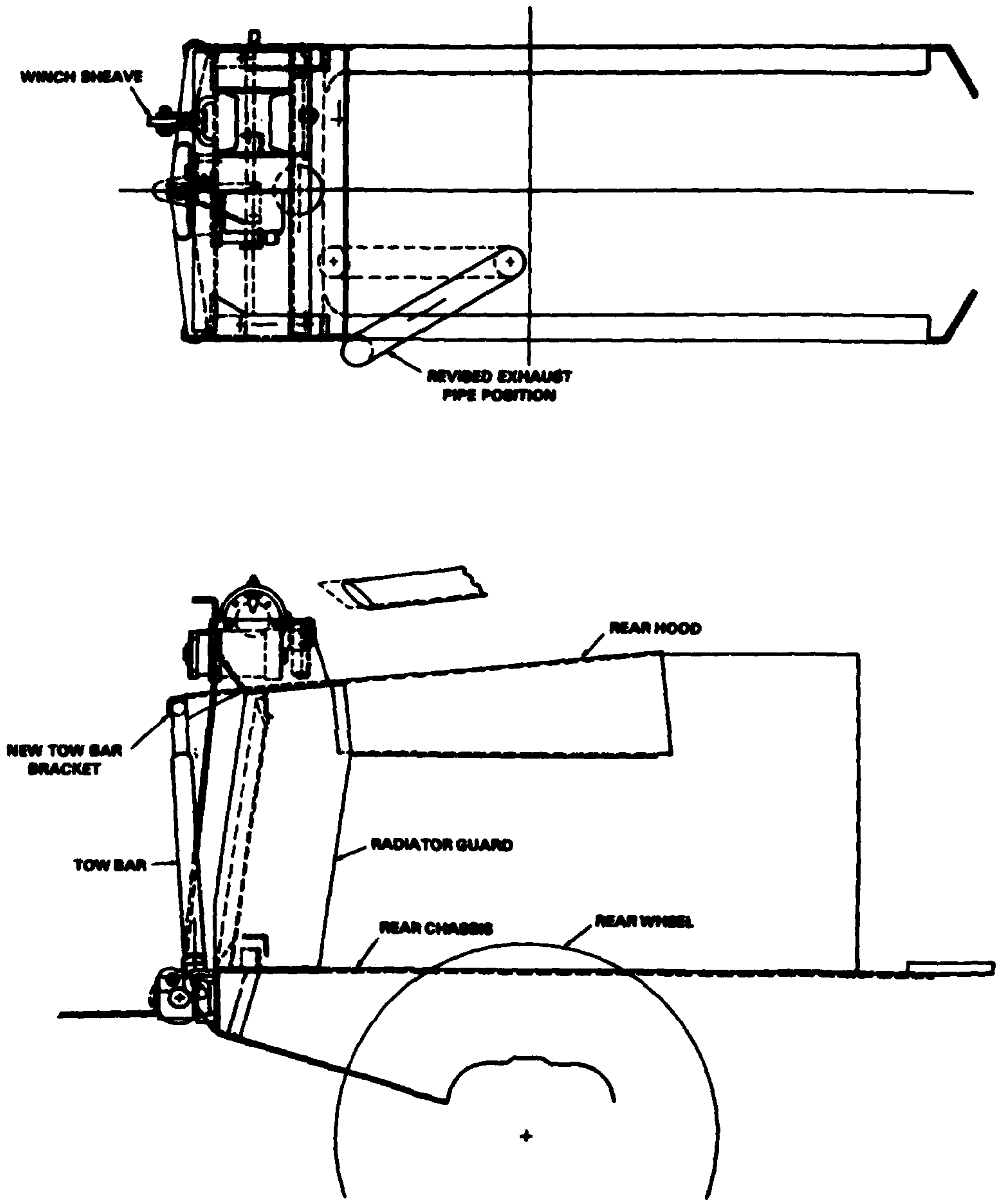

Figure 18. Winch Installation, Top and Side Views

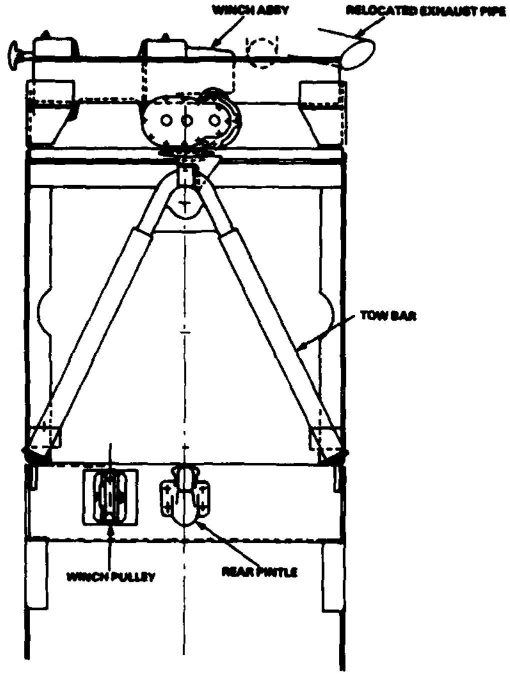

Figure 19. Winch Installation, End View

Summary

The gradability studies showed that the MC4000 should prove to be a good auxiliary mover for the M198 howitzer. It should have little trouble maneuvering the M198 on most road beds, from concrete to gravel.

On off-road firm ground, the MC4000 can handle the M198 on 10° to 15° hills for the stowed configuration and 5° to 10° for the towed configuration; for off-road, soft-soil conditions it can handle the M198 on hills up to 10°. Under extremely soft conditions, two MC4000s operating in tandem can handle the M198 on hills up to 10°. The MC4000 can cross 6- to 7-in.-diameter log-type obstacles at creep speed and larger ones with a little speed buildup. It should handle the M198 on long ramps in the 15° range, but 20° and over were questionable. The MC4000 can push the howitzer up ramps more consistantly than it can pull them because the back wheels of the MC4000 would get "light" on ramp angles over 15°. In the towed configuration, the required traction coefficient is somewhat higher, and the limits will likely be under 15°--once again limited by traction, not power or stability.

The proposed removable/storable front pintle is located so that the forks do not have to be removed for moving operations. Since greater articulation angles were allowed between the MC4000 and M198 than in the Ft. Bragg tests, the muzzle brake should not have to be removed to prevent interference with the MC4000 mast.

All structure and systems of the MC4000 were reviewed for adequacy for this added mission and no significant deleterious effects were anticipated. Supporting data are contained in the J. I. Case Concept Validation and Limitation Study.[3]

Conclusions and Observations

1. The limitation most likely to be encountered by the MC4000 will be a loss of traction on steep hills or soft roadbeds.

2. The concept of using the MC4000 as an auxiliary mover for the M198 howitzer appears valid; no major limitation was discovered.

3. The brake control is in a vulnerable position and needs to be redesigned.

4. The hitch design is limited in the left-hand approach to the howitzer trails, requires more welding and modification than desired, and needs fork-holding straps to make the system viable. Another hitch method could prove superior.

FEASIBILITY ANALYSIS, PART 2

Further refinements and improvements on the design of the PIP were made as the details for the prototype units were worked out.[4]

The necessity for a simpler pintle hitch that would be functional on both mast types fostered an ingenious solution that eliminates field welds and increases articulation. The controls on the howitzer brake activation system were relocated, and a thermal circuit breaker, which should eliminate possible damage by overloading, was incorporated on the winch.

The PIP kit and the M4K mast add about 3 to 12 percent, respectively, to the weight of an MC4000, slightly reducing its speed and gradability performance. However, there is a weight increase on the rear axle in both cases, and since the MC4000 is generally traction and not horsepower limited, the extra weight could add to the vehicle's performance.

The MC4000 should encounter little difficulty in handling the howitzer either on or off landing crafts. The MC4000 should be able to handle the M198 unaided aboard the LPH and LHA and to handle the ramps on the LSD and LST; however, it may have trouble negotiating the long, steep ramp on the LPD. Any no-go situation will probably occur when maneuvering up a soft, sloping beach.

In addition, handling the howitzers on the C130, C141, and C5A aircraft and interfacing with other howitzers should pose no problems for the MC4000.

The stress analysis checks made on the highly loaded parts of the PIP kit and basic machine revealed no areas of excessive stress.

Pintle Hitch

An investigation was conducted to determine if there was a pintle location other than that proposed that would not require the welding of an attaching means to the mast. Figure 20 shows a location beneath the fork that would not require welding. In addition, this location would provide virtually unrestricted articulation, would not restrict the MC4000 approach angle for picking up an M198, and would not require the forks to be held up in a stowed position.

The only disadvantage in this new pintle location is the distance from the front axle. With a 30-in. pintle height and mast tilted back 20°, the pintle "reach" (distance from front axle to pintle) increases from 36 to 45.6 in. for the standard mast and from 43 to 52.3 in. for the M4K mast. This would result in 350 to 400 lb (600 to 650 lb for the M4K mast) being shifted from the rear to the front axle of the MC4000 tested at Fort Bragg. However, this weight shift should be offset by the added weight from the total PIP kit. The kit will add approximately 315 lb to the MC4000, and the center of gravity of the kit (with pintle on the fork) is within 10 in. of the rear axle. Therefore, the new pintle location should cause little change in performance from that of the Fort Bragg tests.

Designs for the fork-mounted pintle were developed for both the standard MC4000 and the M4K masts (Figures 21 and 22, respectively). Every effort was made to provide a single hitch, interchangeable on the MC4000 or M4K mast. About 90 percent of the hitch construction was identical. The tolerance stack-up on the M4K hitch required a series of attachment holes so that it would function on any M4K mast. The multiple-hole requirement and the basic configuration difference of the masts would not allow interchangeable hitches without an undesirable modification to one or both masts. A storage bracket for the hitch was devised for the side of the battery box.

The MC4000 hitch concept meets all the design criteria except that it cannot be stored without disassembly. In both designs, the hitch could be removed by extracting only one pin; it could then be stowed and secured nearby with the same attachment pin.

The M4K mast must be shifted 14 in. before the hitch can be attached. This centerline position of the hitch bracket prevents any side shift capability on the mast.

The hitch design change does not change the gradability, obstacle crossing, or vehicle stability performance.

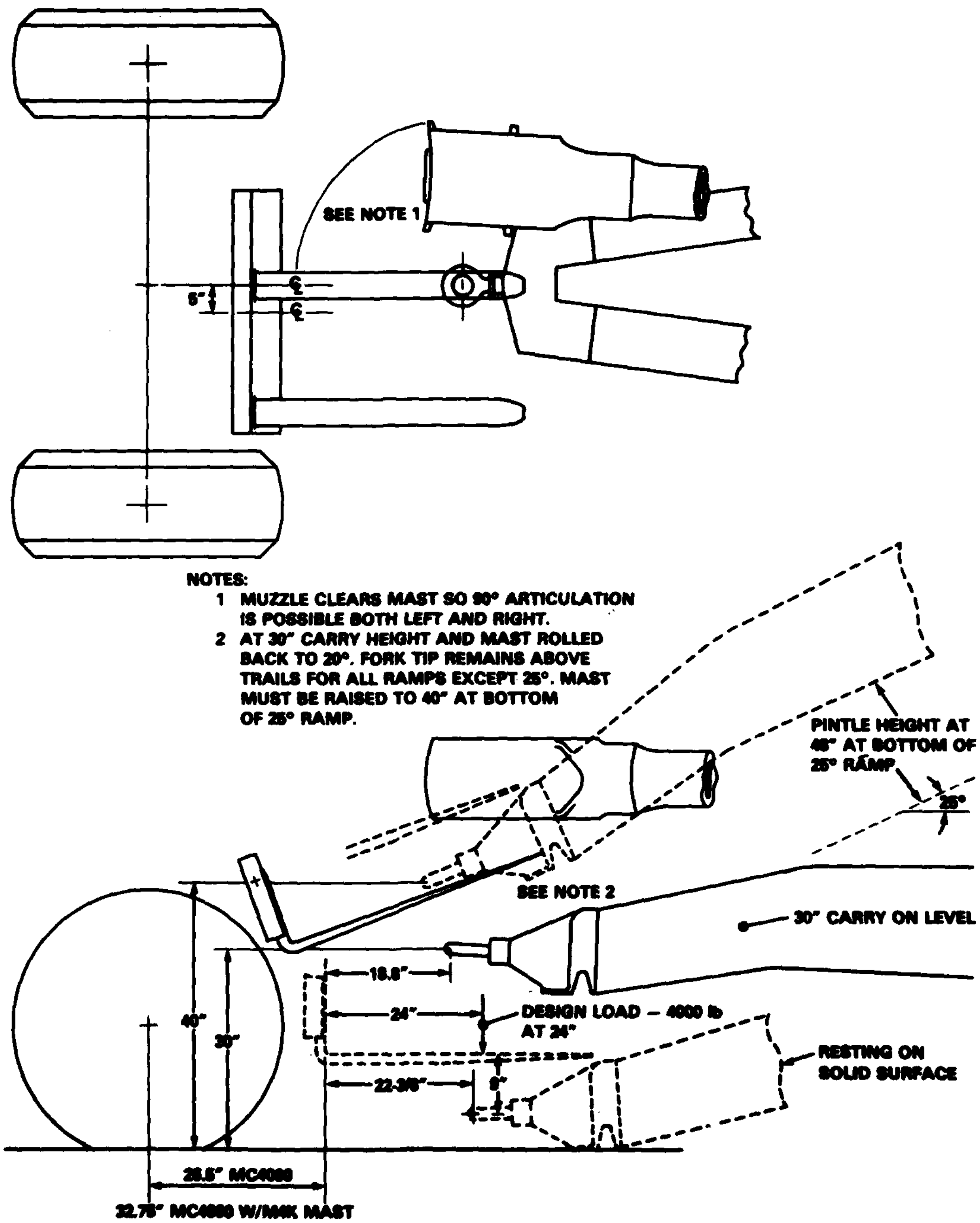

Figure 20. Revised Pintle Location

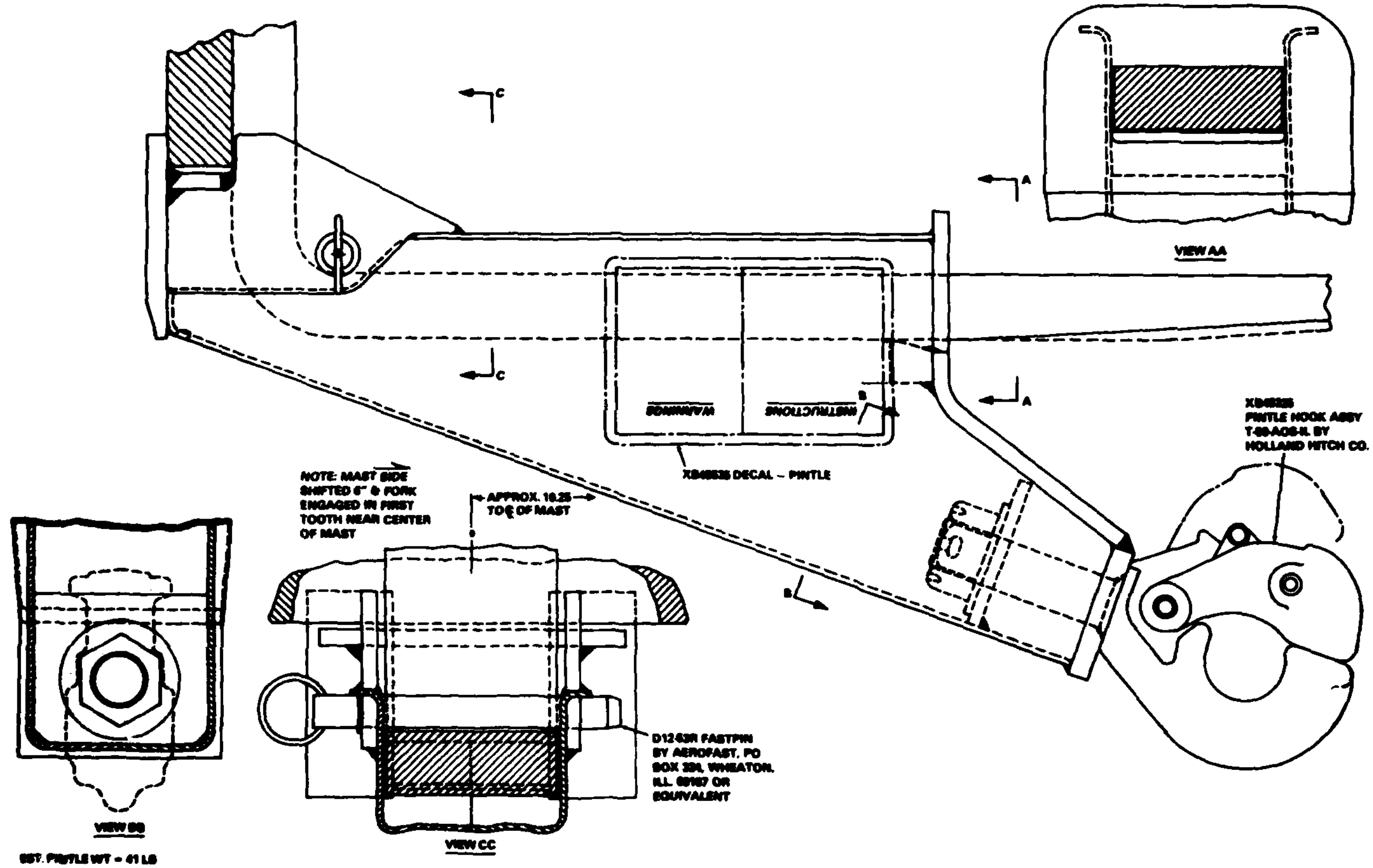

Figure 21. MC4000 Pintle Hitch Version

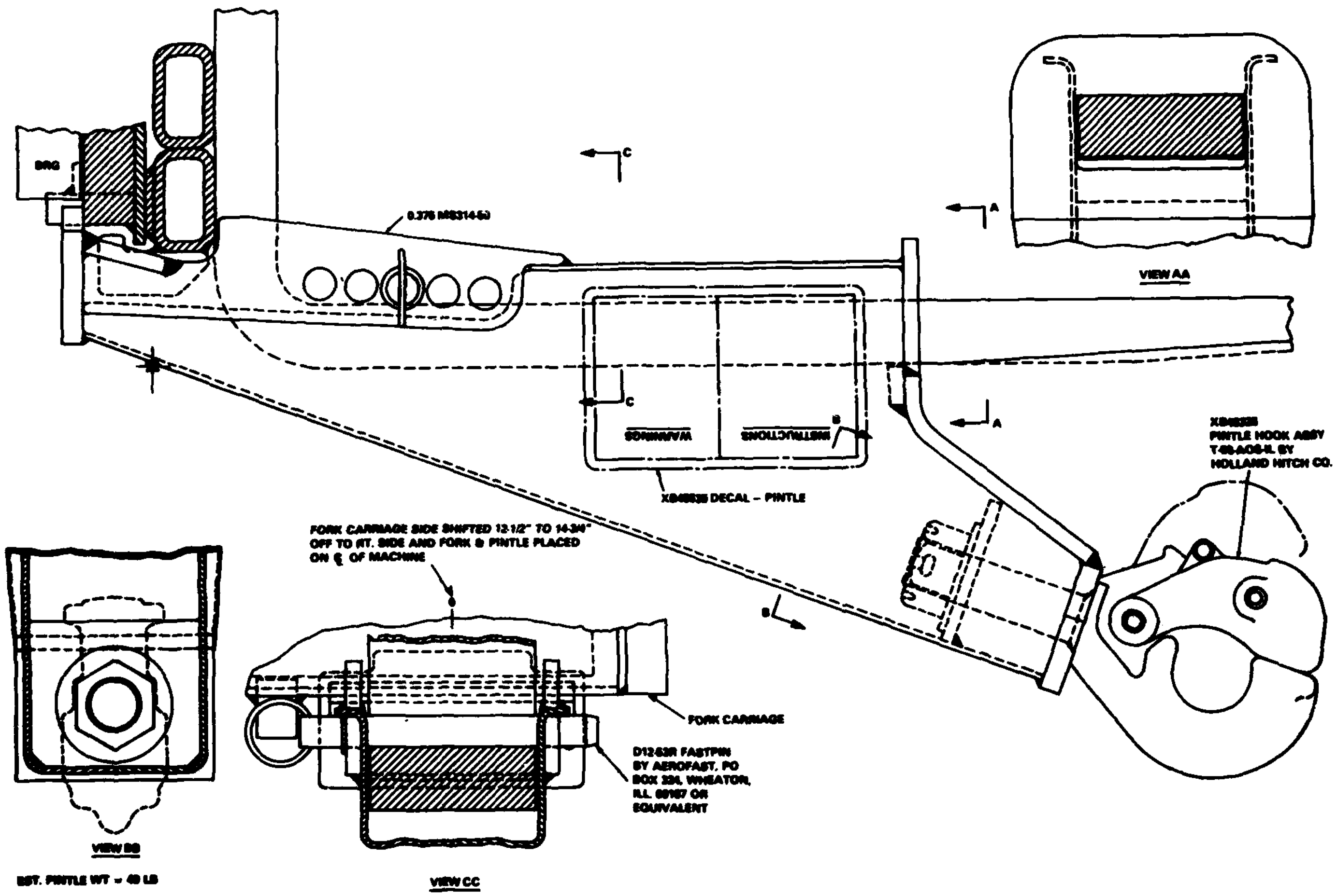

Figure 22. M4K Pintle Hitch Version

Other Component Changes

The air brake control system and winch assembly are shown installed on an MC4000 in Figure 23. Because its earlier position was precarious, the air brake control panel was mounted permanently on the operator console to obtain good operator access.

While there were no changes in the winch design, the pulley was revised slightly, with minor improvements to the shape of its parts. An electrical overload circuit breaker (thermal type, manual reset) was added to the winch circuit to help prevent damage to the winch motor and drive system caused by excessive loads and to prevent the cable from breaking (cable breaking strength is 9800 lb and the winch stalls at over 10,000 lb). The 150-amp breaker should limit the line pull to 6000 to 8000 lb (the breaker will hold 150 amps continuous and interrupt the circuit at no more than 195 amps, which should produce 6000 and 8200 lb, respectively.

PIP Kit Effect on Performance

The added weight of the improved PIP kit causes little loss in performance. The speed loss due to the added weight of the M4K mast and the PIP kit was 0.2 to 0.3 mph over most of the grade ranges; the worst speed loss occurs at 1 mph in the 8- to 15-mph range for the 4- to 8-percent grades. The added weight of the PIP kit alone produces less than half of this effect.

The computer program used previously was again used to determine traction changes caused by the weight increase from the PIP kit and M4K mast. There is little difference in required traction for the standard and M4K masts on ramps.

Ship and Aircraft Handling

The enlarged mission of the MC4000 will include handling the M198, M114, M101, and M102 howitzers on the following aircraft and ships:

Aircraft	Ships
C130	LPD
KC130	LPH
C141A	LHA
C141B	LCU
C5A	LCM-6
	LCM-8

Descriptions of theoretical ship/aircraft ramp handling and landing capabilities and considerations are summarized in Tables 3 and 4, respectively.

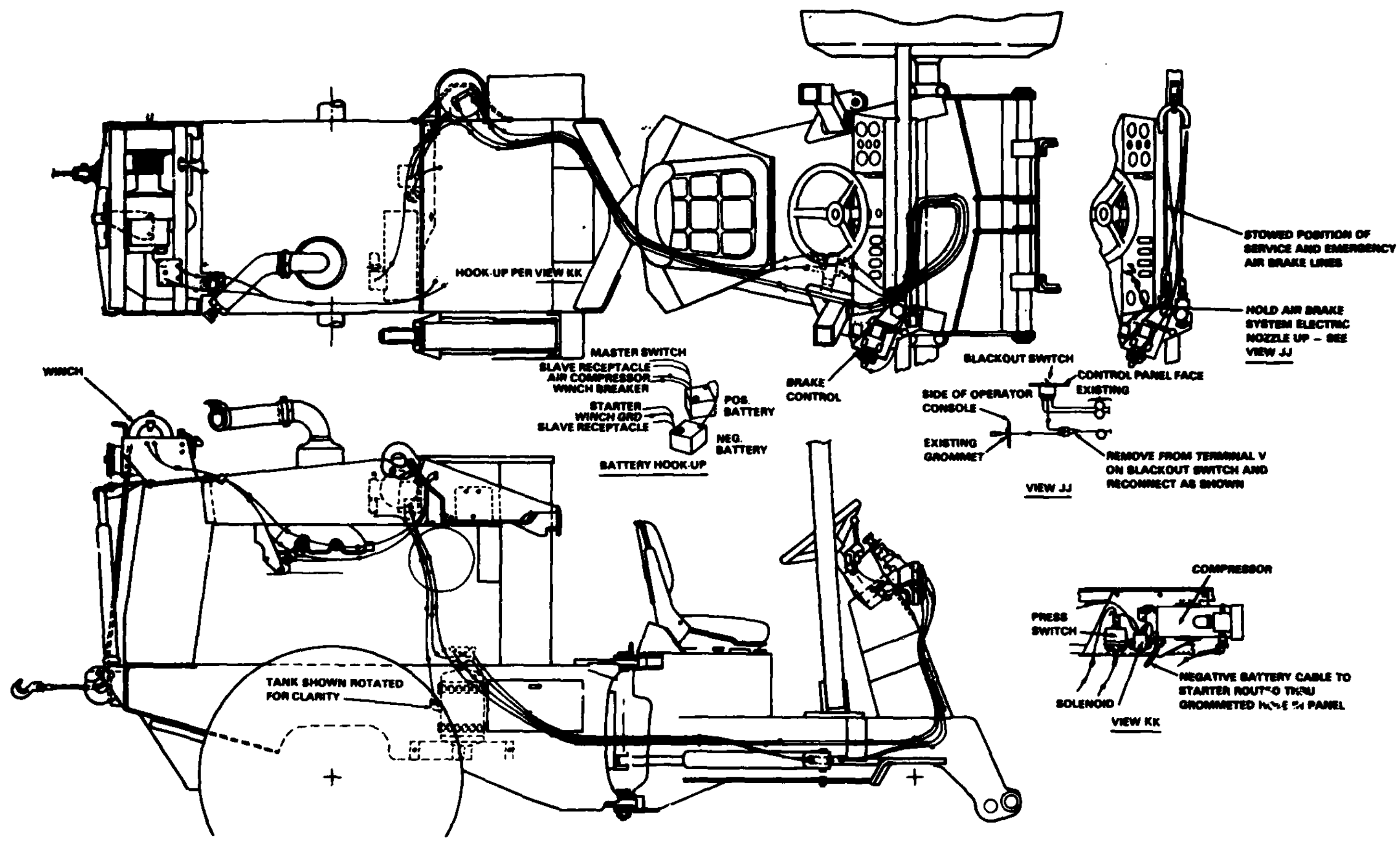

Figure 23. Air Brake Control and Winch Assembly

Table 3. Theoretical Ship/Aircraft Ramp Handling (M198 Stowed)

Ship/Aircraft	Ramp Description: Length (ft)	Ramp Description: Angle (°)	Ramp Description: Width (ft)	Ramp Description: Overhd Clearance (ft)	Ramp Description: Ramp Notes	Reqd. Traction Coef.: Pushing	Reqd. Traction Coef.: Pulling	Likelihood of Success*: Pushing	Likelihood of Success*: Pulling	Likelihood of Success*: Overall
Ships										
LCM-6	10.3	18 V	10.9	--	1-3/4- x 1/3-4/-in. traction angles on 7-in. centers	0.38	0.36	Good	Good	Good
LCM-8	12.8	34.5 V	14.5	--	1- x 1-in. traction bars on 9-in. centers	0.72	0.68	Good	Good	Good
LCU-1610	17.8	26 V	14	--	1- x 1-in. traction bars on 9-in. centers	0.55	0.51	Good	Good	Good
	~10	8 V	18	--		0.19	0.17	Good	Good	
LPH	No Ramps			9.8		--	--	Good	Good	Good
LPD	60	25	10 MIN	10 MIN	1- x 1-in. traction bars on 9-in. centers	0.92 EHL	0.98 ESL	None	None	None
	72	12				0.47	0.48	Good	Good	
LSD	38	19	12 MIN	10 MIN	1- x 1-in. traction bars on 9-in. centers	0.70	0.75*	Fair	Poor	Fair
	56	10				0.39	0.40	Good	Good	
LHA	124	14.5	10 MIN	11 MIN	1- x 1-in. traction bars on 9-in. centers	0.54	0.57	Good	Good	Good
	72	14.5				0.54	0.57	Good	Good	
	72	2				0.13	0.13	Good	Good	
	42	6				0.26	0.26	Good	Good	
	34	10				0.39	0.40	Good	Good	
LST	110	21	10 MIN	13.6 MIN	Special traction grating ramp	0.76	0.81 ESL**	Fair**	Poor	Fair
	66	21				0.76	0.81 ESL**	Fair**	Poor	
	28	18 V				0.66	0.70	Fair	Fair	
Aircraft										
C&KC 130	10	11.5 to 15	[illegible].5	9		0.26 to 0.33	0.24 to 0.31	Good	Good	Good
C141 A&B	11.1	11	10.2	8.8		0.25	0.23	Good	Good	Good
C5A	27	2.7/13.3	13	9.5	Rear door aft/fwd kneeled	0.11/0.36	0.15/0.51	Good	Good	Good
	~24	10.3/29.5	19	13.5	Forward door fwd/aft kneeled	0.25/0.65	0.23/0.60	Good	Good	
CH-53	7.2	12.3	7.2	6.5	M198 carried suspended	NA	NA	NA	NA	Good

NOTES: EHL = exceeds horsepower limit; ESL = exceeds stability limit (rear wheels lift); V = ramp angle variable, max. shown
* likelihood that MC4000 can handle the M198 unaided on the ramp
** exceeds stability limit of MC4000 with M4K mast and near stability limit of unit with standard mast

Table 4. Ship/Aircraft Handling Considerations

Ship/Aircraft	Special Considerations
Ships	
LCM-6	None
LCM-8	None
LCU-1610	None
LPH	M198 too large for cargo elevator (37.3 x 9.2 ft vs 7 x 11 & 7 x 17 ft); aircraft elevators (34 x 50 ft) OK
LPD	None
LSD	None
LHA	Lower vehicle stowage is restricted for M198 by overhead limitations
LST	MC4000/M198 coupled in-line exceeds diameter of turntables (37.3 ft overall, 32.1-ft C-C axles vs 30-ft dia & 40-ft clearance table)
Aircraft	
C&KC 130	M198 axle load in towed (extended) configuration exceeds allowable load on floor & ramp (15,100 vs 13,000 lb)
C141 A&B	M198 wheel load in stowed & towed configurations exceeds the allowable load on treadways (7550 & 6050 lb vs 5000 lb flight & 7500 lb loading)
C5A	None
CH-53	MC4000 wheel load exceeds allowable limit of 1725 lb

Howitzer Interface Compatibility

Ramp operations for the M198, M114, M101, and M102 are shown in Figures 24 through 27. Table 5 summarizes the suggested carrying heights for all the howitzers. Interface with any of these howitzers will cause no problems for the MC4000 beyond possible interference in certain positions, and normal operator control should alleviate these.

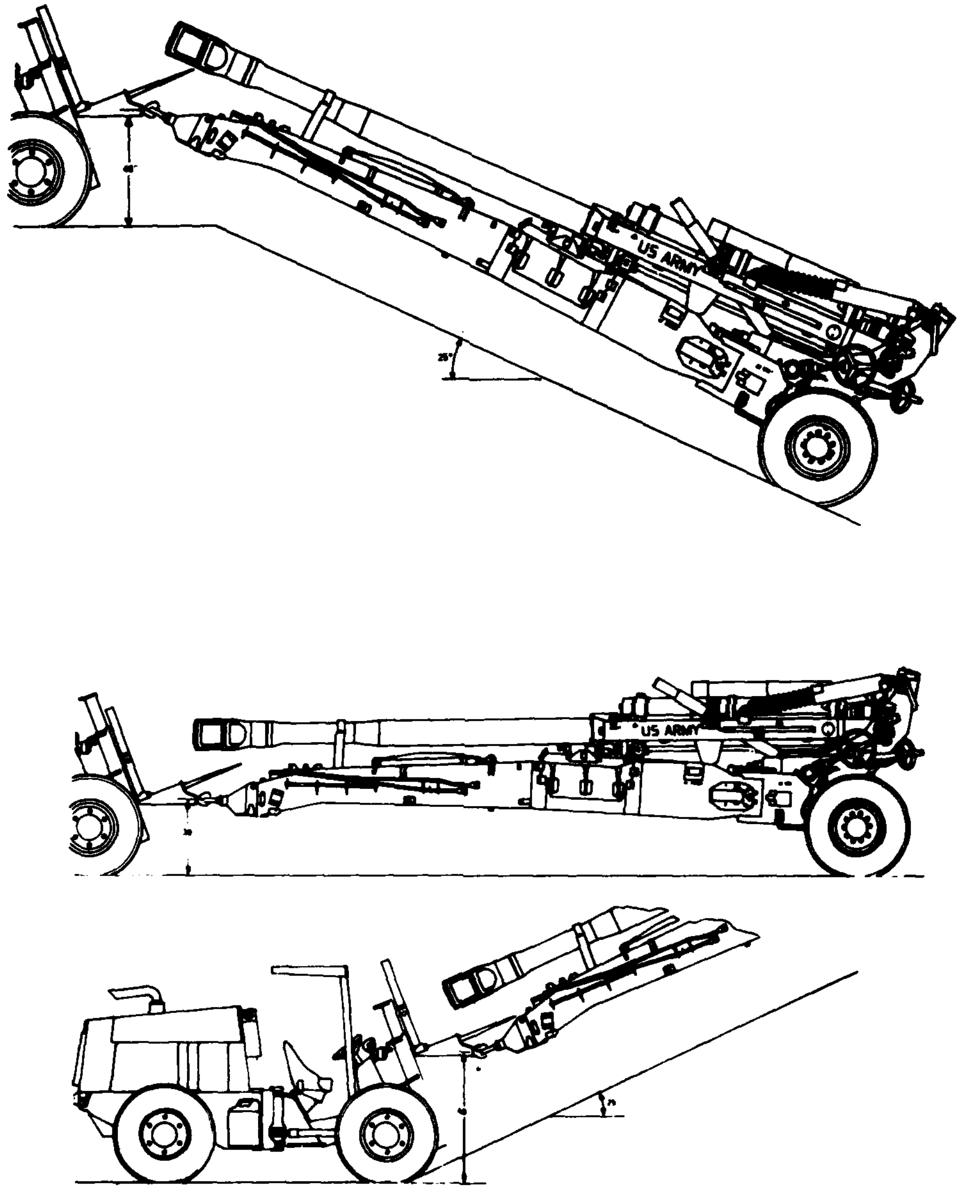

Figure 24. MC4000/M198 Ramp Operation

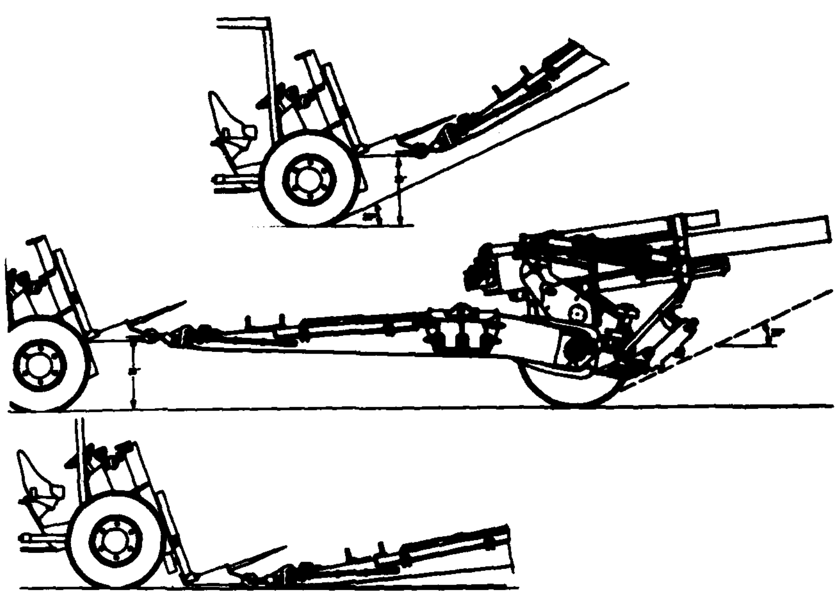

Figure 25. MC4000/M114A2 Ramp Operation

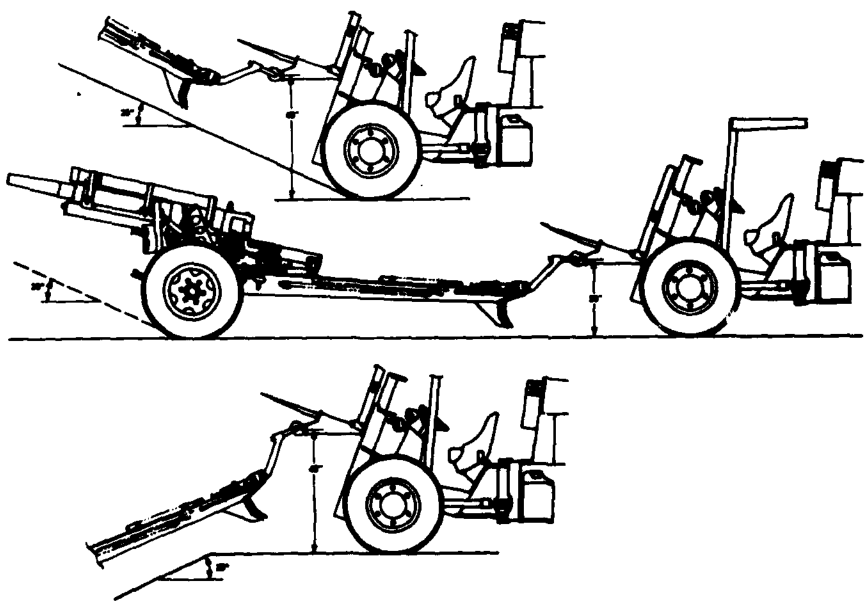

Figure 26. MC4000/M101A1 Ramp Operation

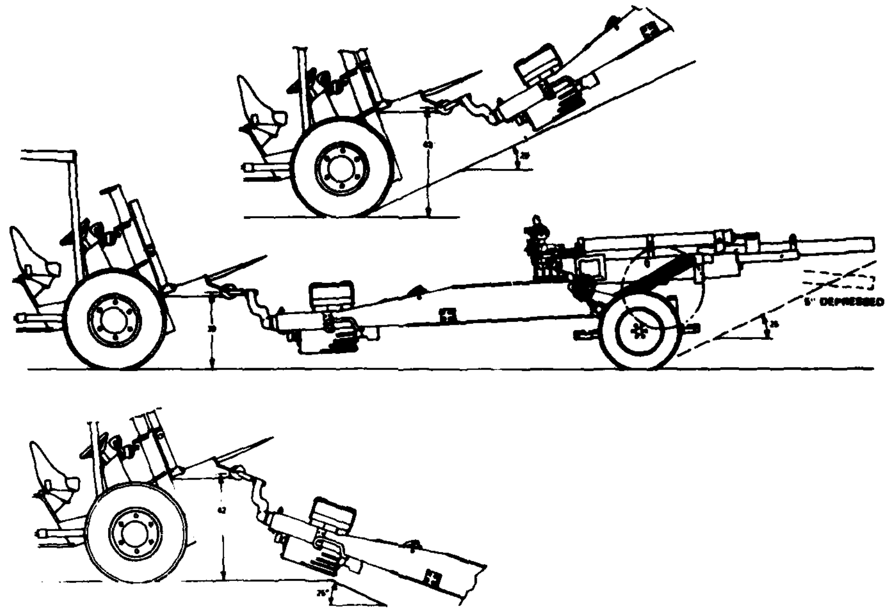

Figure 27. MC4000/M102 Ramp Operation

Table 5. Howitzer Carrying Height Summary

Howitzer	Bore (mm)	Howitzer Weight (lb)	Approximate Pintel Load (lb)	Normal Operation (in.)	Top of 25° Ramp (in.)	
					(1)	(2)
M102	105	3,020	110	30	40	42
M101	105	4,980	190	30	36	44
M114	155	12,920	600	30	24	22
M198 towed	155	15,600	500	30	40	40
M198 stowed			3,500	30	40	40

(1) minimum -- limited by interference between howitzer undercarriage and top of ramp
(2) minimum -- limited by interference between fork and trails of howitzer

In all cases, the barrel of the howitzer must be elevated high enough to prevent interference between it and the ramp.

TEST RESULTS

PRELIMINARY INTERFACE AND BRAKE SYSTEM EVALUATION

Purpose

In-house testing of the PIP kit by J. I. Case was completed by early May 1980. Structural adequacy of the pintle hitch and the rear-mounted winch was checked. However, two requirements had to be met before the PIP MC4000 could go aboard Navy ships: (1) the vehicle required certification of design objective and (2) a determination had to be made that the equipment added to the MC4000 would not affect the basic operation, performance, or safety of the forklift beyond the effects of the added weight. Therefore, a test was scheduled at Rock Island Arsenal to provide the certification and final interface and brake system performance evaluation in advance of field trials to be held in July and August 1980.

A GFE-supplied MC4000, modified by J. I. Case, was shipped to Rock Island Arsenal and was attached to an M198. The MC4000 is shown with the pintle hitch in position and stowed in Figures 28 and 29. The winch and brake control are shown in Figures 30 and 31. The tests were conducted in accordance with paragraphs 2.0 and 3.1 of the recommended test plan.[5]

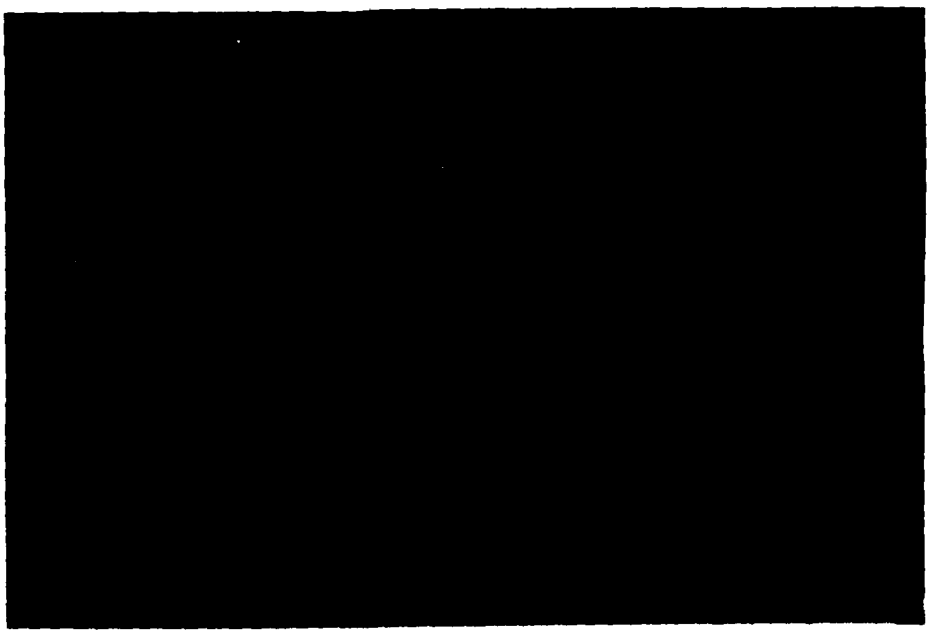

Figure 28. Prototype Pintle Hitch Installed on MC4000

Figure 29. Prototype Pintle Hitch Stowed on MC4000

Figure 30. Cowl-Mounted Prototype Winch on MC4000

Figure 31. Prototype Brake Control for Trailered Loads by MC4000

Conclusions

The following conclusions were reached based on the Rock Island tests:

1. The brake system of the vehicles performed as anticipated, and the MC4000 handled the M198 very well on hard-surfaced roadbeds.

2. The fork-mounted pintle engaged the lunette on the M198 satisfactorily, confirming that the pintle should provide all required articulation between the vehicles.

3. These trials on 15° and 32° ramps provided a limited confirmation of the analysis of ramp handling.

4. Brake pressure measurements confirmed that the sizing of the components (compressor and storage tank) met the assumed braking standards.

5. The nonrecommended braking practice of applying only the howitzer brakes in a panic stop, with the howitzer going in front of the MC4000, did not cause jackknifing; however, it did cause the howitzer to pitch forward when being towed. This action could be eliminated by locking the

carriage to the mast or adding a removable stop. However, it caused no damage, and a lock or stop would impair one of the basic mast features (the ability to elevate the pintle), so no change to the design is recommended.

6. The air supply tank should be rotated to alleviate a slightly pinched air hose and move the quick coupler on the side of the tank away from the tire.

7. A clamp should be attached on the right side of the pintle to hold the air hoses from the howitzer off the ground.

8. When an attempt was made to rotate the mast with the pintle in position and holding the howitzer lunette, the pintle did not allow the mast to rotate; neither the pintle nor the mast were apparently damaged.

9. The low brake pressure warning buzzer is not very loud.

10. The pintle load in the stowed condition was 3800 lb compared with the 3500 lb used in the analysis.

11. The air hoses on the M198 were not appropriately identified as either "service" or "emergency," which can lead to confusion when coupling the air lines.

The test report contains more details of the Rock Island tests.[6]

AMPHIBIOUS COMPATIBILITY TEST

Purpose

The Marine Corps scheduled a test to validate the procedures and concept for the amphibious embarkation of the M198 howitzer. The test included the use of the primary mover (M813 5-ton truck) and the designated ammunition mover (MC4000 rough-terrain forklift) aboard various amphibious ships and landing craft.

Objective

The main objective of this exercise was to determine the beach mobility and deployability of the M198. This report concerns only the testing directly affected by the use of the MC4000. Other aspects of the M198 performance may or may not be reported depending on its relevance to the MC4000 as the solution to the auxiliary mover problem.

The evaluation took place on the following ships and landing craft:

- LHA-2, USS SAIPAN

- LPD-13, USS PONCE
- LST-1196, USS HARLAN COUNTY
- LSD-34, USS HERMITAGE
- LCM-8
- LCU

The land test sites were restricted to unprepared beach areas of the Naval Amphibious Base (NAB), Little Creek, Virginia. Some preliminary work occurred on hard-surfaced infantry test areas near the Amphibious School.

Hardware

The major hardware used in the amphibious evaluation is described below.

Hardware	Description
M198 155-mm towed howitzer	Will replace the M114A2 and M101A1 towed howitzers in the Marine Corps. Is helicopter transportable, weighs 15,600 lb, and requires a crew of 10. Two howitzers were evaluated.
M813 5-ton truck	Diesel-powered 5-ton truck designated as the prime mover for the M198. Will replace the M54 and M35 trucks in the artillery battery. Two 5-ton trucks were evaluated.
MC4000 RT forklift	Designated as auxiliary mover for the M198 howitzer. Two MC4000s were evaluated--both were articulated 4000-lb forklifts modified with a prototype PIP kit consisting of pintle hitch, auxiliary brake system, and winch; one was modified with an M4K mast.

Procedure

The test procedure was designed to get the equipment on and off ships and landing craft and across beaches as quickly, efficiently, and safely as possible. The test was conducted in accordance with the Marine Corps amphibious compatibility test plan.[7] The test schedule for the seven basic events is given in Table 6.

Table 6. Test Schedule for Amphibious Compatibility Test

Date	Ship/Landing Craft	Test Area	Event
30 Jul	LCM-6 & LCM-8	Red Beach 4 and infantry training area	Preliminary work and equipment familiarity
31 Jul	LHA-2		Embark, debark, and maneuver on board LHA-2
1 Aug	LPD-15		Hoist vehicles on and off and maneuver on board LPD-15
5 Aug	LST-1196		Embark, maneuver on board, and stow vehicle on LST-1196
6 Aug	LST-1196		Disembark from LST-1196 over causeway and attempt beach crossing
7 Aug	LSD-34		Hoist vehicles on and off and maneuver on board LSD-34
8 Aug	LCU-1658 & LCM-8	Mud flats and Red Beach 1	Load out and land LCU-1658 and LCM-8 from the mud flats to Red Beach 1

Results

The following results were obtained from the M198 howitzer amphibious compatibility test conducted during the period 28 July to 9 August 1980.

30 July. After acceptance of the two PIP MC4000s from Norfolk, the forklift operators adapted well to the new role for the MC4000 as M198 auxiliary mover. Their skill and confidence in the maneuvering capability increased rapidly so that loading of the LCM-6 and LCM-8 boats was conducted with a minimum of difficulty on the first day. This was due to the expertise and enthusiasm of the forklift operators as well as to the superior automative characteristics of the MC4000/M198. The forklift's short articulated wheelbase coupled with the long wheelbase from tractor to gun and high visibility of the pushing configuration provided a very precise maneuvering capability.

One man was able to quickly effect a hookup or drop of a towed or stowed M198 with the pintle hitch mounted on the lifting position of the forklift mast. The MC4000 and MC4000/M4K hitches are shown in Figures 32 and 33. The present hitch attachment pins proved to be too soft; they deformed under heavy loads during some of the early evaluations.

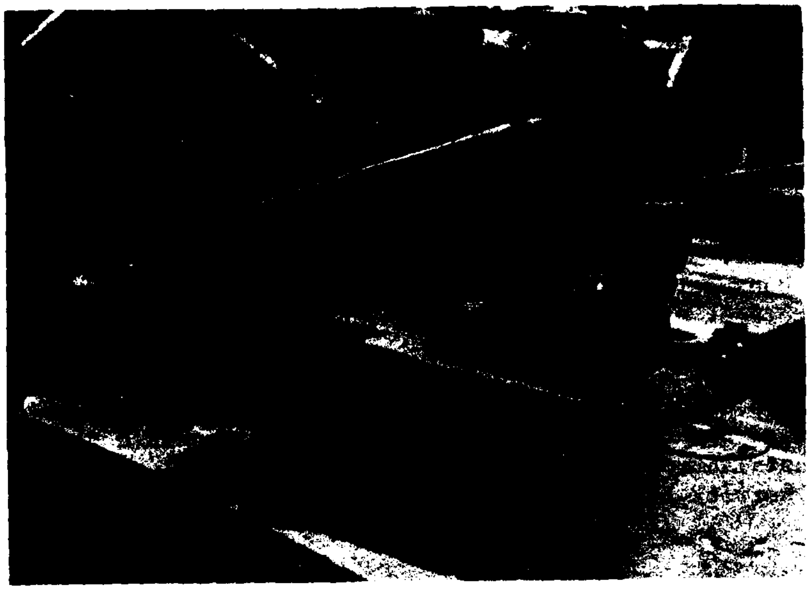

Figure 32. MC4000/Old Mast Pintle Hitch

Figure 33. (MC4000/M4K)/M198 Hookup

The M813/M198 would not load out on an LCM-6, but the MC4000/M198 combination would do so in stowed or towed conditions with a barrel offset in the towed condition to clear the coxswain's station and the detachment of the MC4000. The M813/M198 would load detached on the LCM-8 but required a barrel offset and split trails similar to those on the gun shown on the LCM-6 in Figure 34. The MC4000/M198 would load on an LCM-8 tactically in a stowed or towed condition. At certain ramp angles, the M198 trails scraped those of the LCM when loaded by the M813 (Figures 35 and 36). The MC4000's ability to lift the M198 trails above the interference eliminates this loading problem.

The MC4000/M198 in towed condition experienced a mast run-up when pushing the M198 over the 6-in. step on the LCM-8 ramp, caused by light hitch loads and large pushing power. Although not a particularly dangerous situation, this can be exciting if unexpected. Experience, reduced approach speeds, tilting the mast forward, correct hitch height, and maneuvering the howitzer one wheel at a time over obstructions will help prevent this condition.

The operators experienced winch declutching difficulties during this familiarization period because they did not follow the prescribed break-in exercises in the Installation Procedures and Operation and Maintenance Instructions.[8] After correct break-in exercises, the winch functioned correctly.

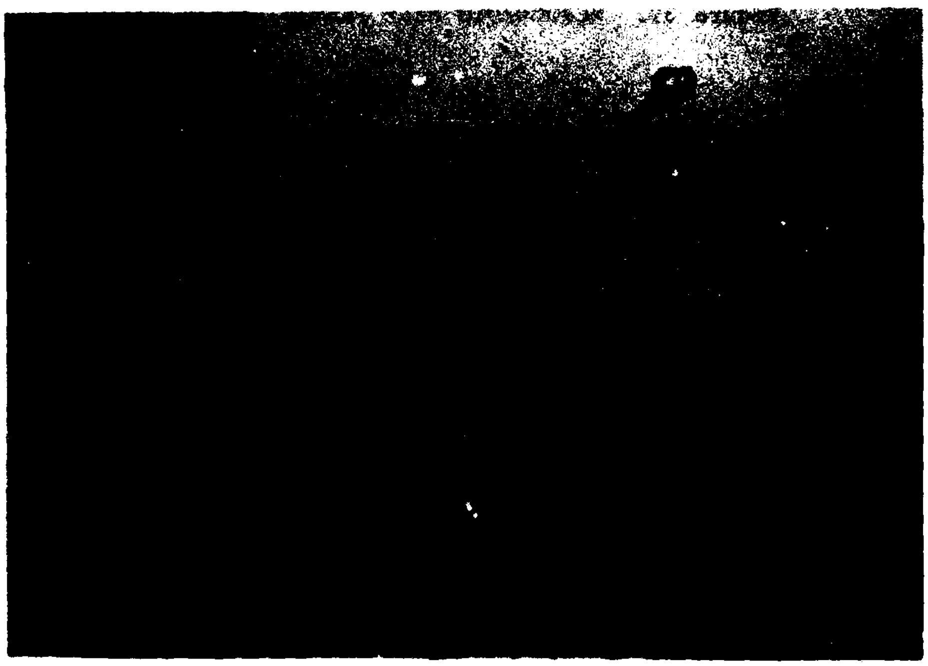

Figure 34. M198 Loaded on LCM-6 with Barrel Offset and Split Trails

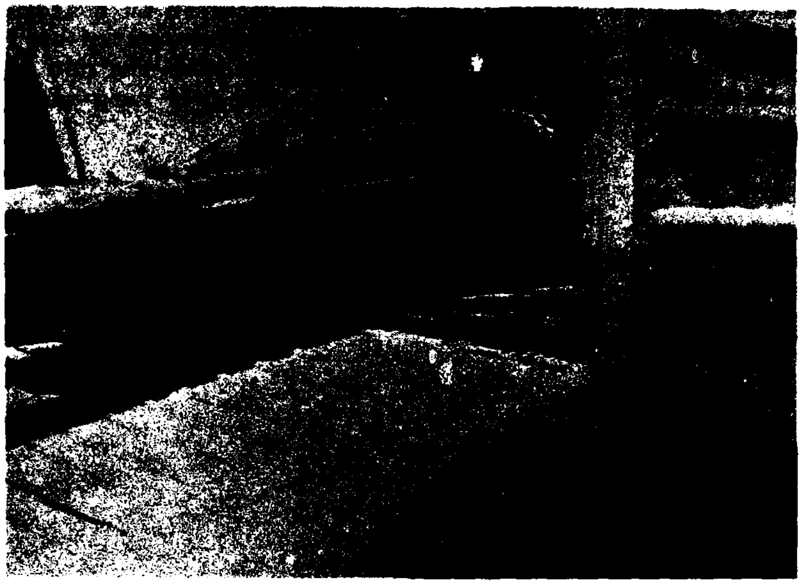

Figure 35. M813/M198 Trail Interference on LCM-6

Figure 36. M198 Trail Damage on LCM-6

31 July. The M813/M198 attempted a port hatch entry on the LHA-2. The combined length of the truck and howitzer made it difficult to line up on the ramp, and it could not negotiate the required turn inside the hatchway. The MC4000 pushed the M198 up the port hatch ramp with only a 2-in. clearance and negotiated the inside turn (Figure 37). The MC4000/M198 in a stowed condition pushed and pulled from well deck to flight deck and maneuvered on flight and hangar deck with ease. Although entry on the stern ramp was not attempted, measurements indicated no anticipated problems. The LHA ramp and deck layout is shown in Figure 38.

Figure 37. MC4000/M198 Port Hatchway Entry on LHA-2

1 August. One M813, two MC4000s, and one M198 were lifted to the flight deck of an LPD-15. The MC4000/M198 in stowed condition easily maneuvered on the flight deck, pushed down the 25° ramp to upper vehicle storage, and pushed down the oily ramp to the well deck. The only problem encountered was that the 25° ramp provided only a 2-in. clearance for the M198 tires. The MC4000 pulled the stowed M198 out of upper vehicle stowage with the other MC4000 attached by a nylon line as a safety vehicle. Again, entry of the stern ramp was not attempted, but measurements indicated no problem. An LPD deck layout is shown in Figure 39.

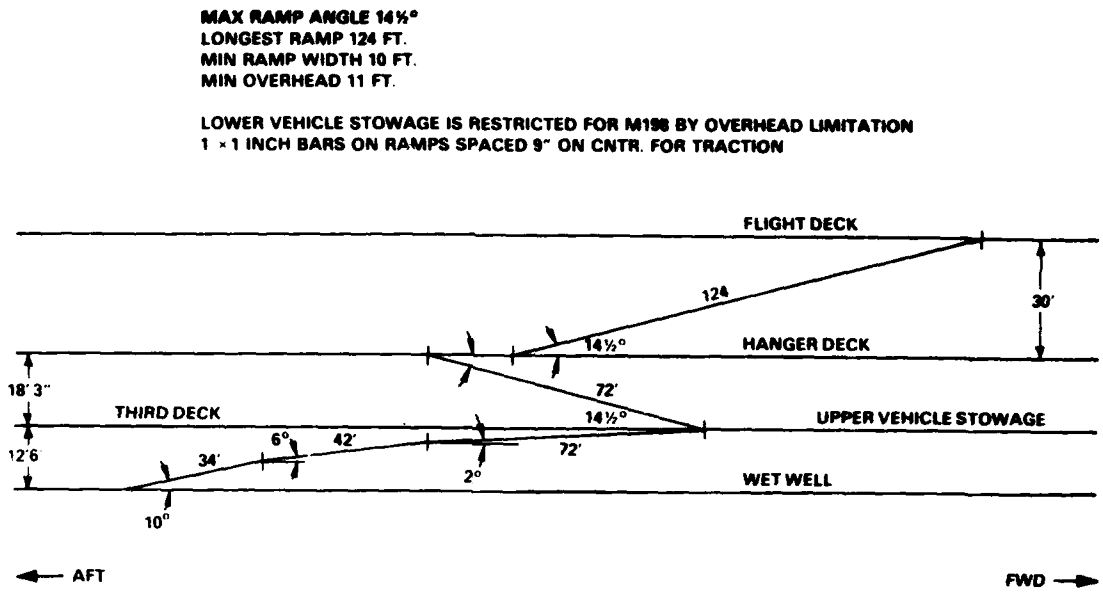

Figure 38. LHA Usable Ramp Layout

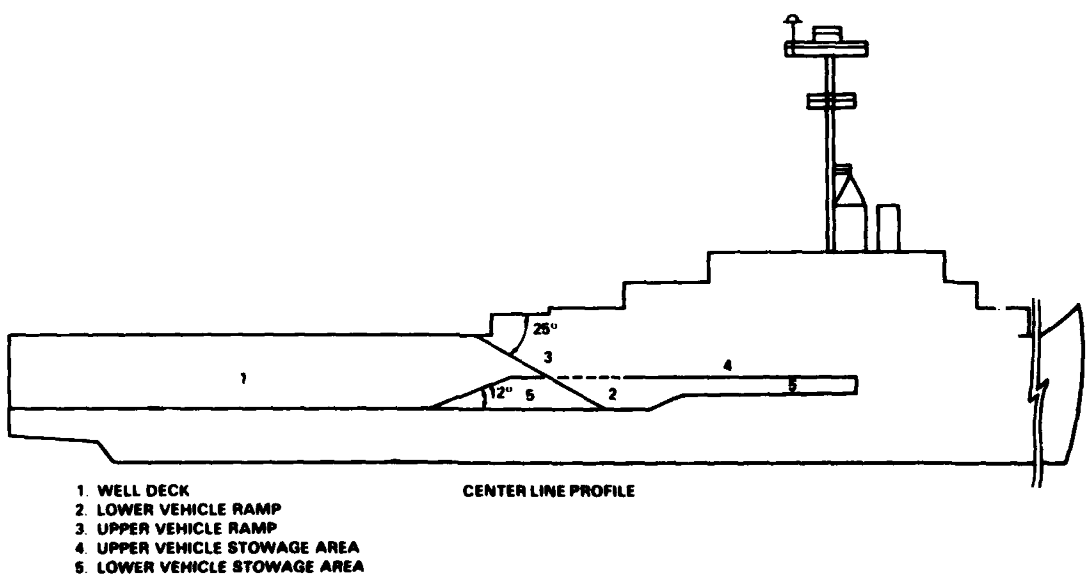

Figure 39. Profile of Amphibious Transport Dock (LPD)

During the 25° ramp exercise, the MC4000 experienced some mast binding and excessive tilt at the deck/ramp junction due to heavy loads and improper braking. With the MC4000 on level decking, the M198 on the ramp, and the brakes locked on both units, the operator attempted to lift the mast and provide a larger howitzer trail clearance; he achieved a marginal success. When the mast is lifted in this configuration (Figure 40), at least one of the vehicles moves or the mast binds and fails to lift the howitzer trails. The hitch should be at the proper height before reaching this point or the gun brakes should be slowly released while lifting the mast.

An abnormal tilt noticed during these operations, caused by heavy off-center loads, was determined not to be a serious condition. It did not cause binding but was rather a nuisance. To correct this, the hitch tine was repositioned on vehicle centerline and held with spacers (Figure 41).

<u>5 August</u>. After a four-day break in activities, the test vehicle embarked on LST-1196 at the NAB pier at Norfolk. The MC4000 pulled an M198 up the bow ramp and down the tank ramp (Figures 42 and 43) without difficulties.

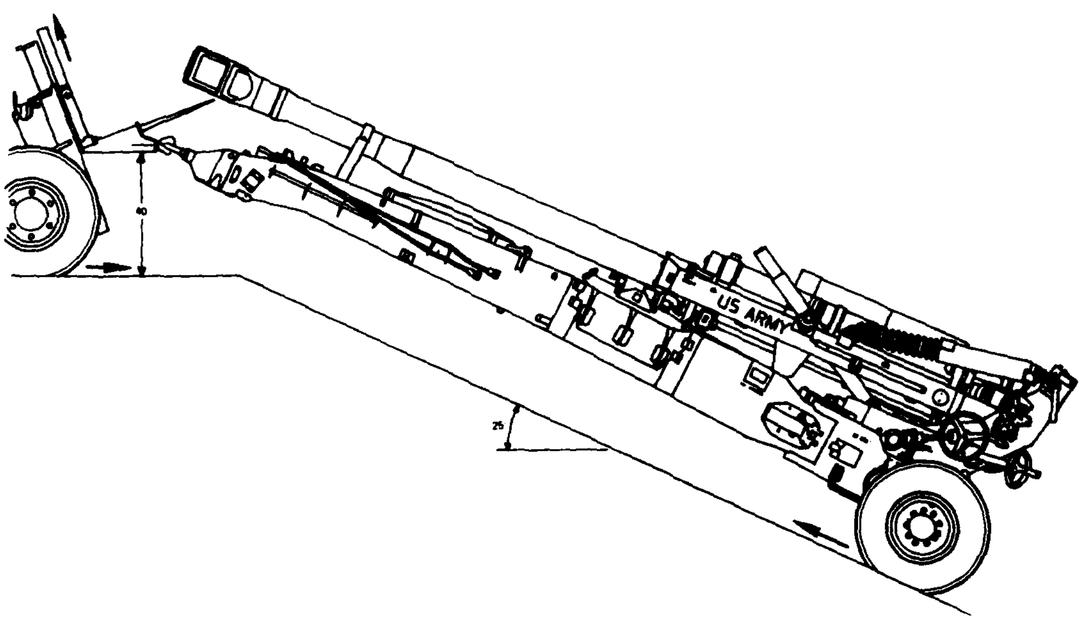

Figure 40. Vehicle Movement Necessary to Prevent Binding During Mast/Hitch Lift

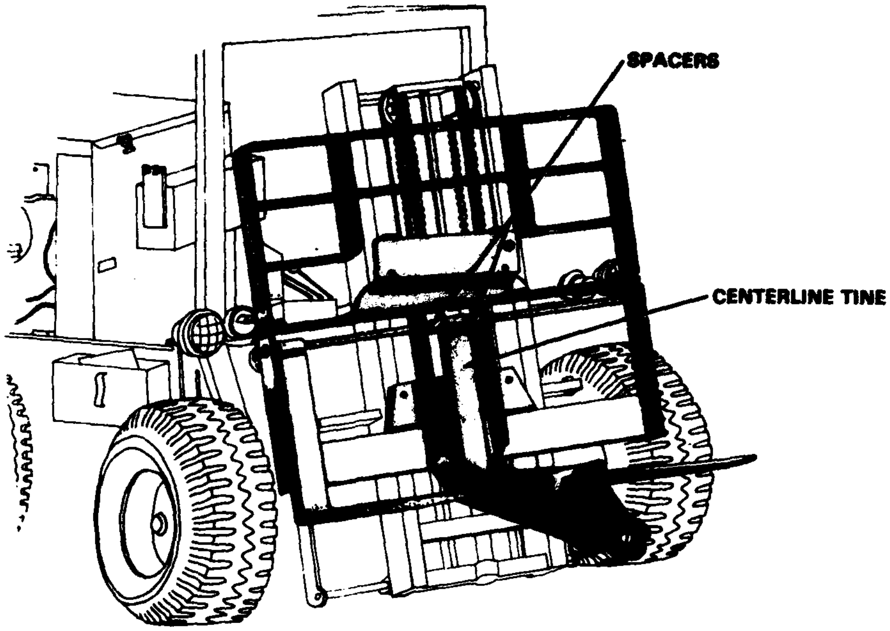

Figure 41. Centerline Towing Configuration for MC4000 Old Mast System

Figure 42. MC4000/M198 Pulling Up Bow Ramp of LST-1196

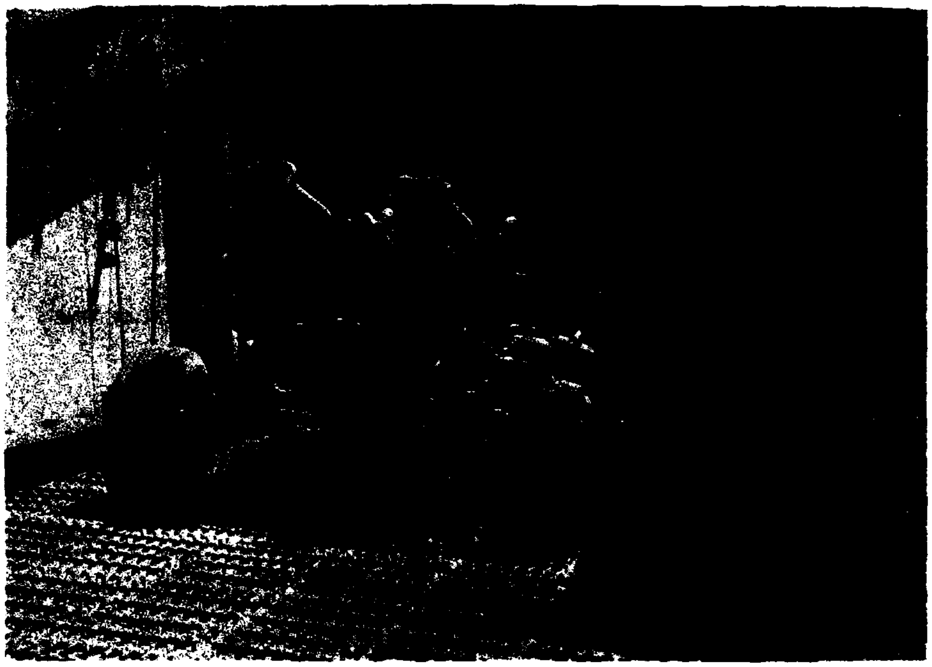

Figure 43. MC4000/M198 Pulling Down Tank Ramp of LST-1196

The M813/M198 combination created a very difficult LST turntable evolution. The howitzer length in towed condition exceeded the turntable rotation diameter, thus requiring the weapon to be stowed. In this condition, the M813/M198 was no longer a viable solution to the turntable evolution. The MC4000 eliminated this problem by placing the M198 in the stowed condition on the turntable, quickly disconnecting and pulling alongside for rotation (Figure 44).

During this LST loadout, the new center position for the hitch rubbed against the lower mast upright crossbar. Under heavy loads, the mast would deflect, causing the hitch to press against the crossbar and forcing the crossbar into the mast base (Figures 45 and 46). Although undesirable, these contact areas did not cause any problems during the testing.

6 August. After leaving the Norfolk pier area, LST-1196 linked up with the Red Beach causeway at Little Creek. The M813/M198 disembarked from the LST without difficulty but immediately became stuck in the very loose sand at the end of the causeway. The vehicle combination was towed by an LVTP-7 to hard surface.

Figure 44. MC4000/M198 Turntable Evolution on LST-1196

Figure 45. MC4000 Hitch at Interference Position on Mast Upright Crossbar

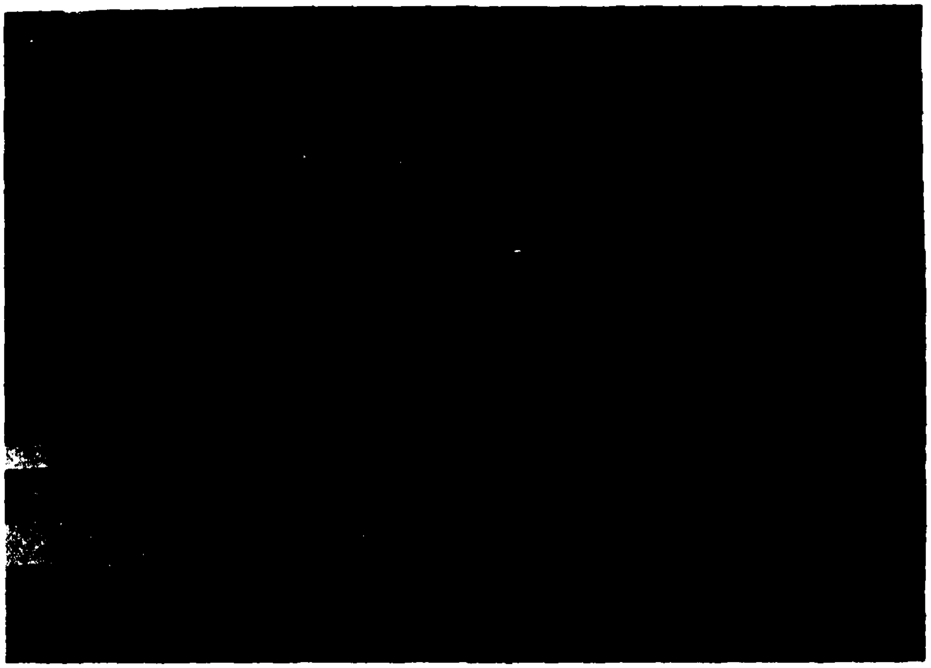

Figure 46. MC4000 Mast Wear Marks

The MC4000 had trouble pulling the M198 out of the tank well; the vehicle obviously experienced a power loss at this time. The operator turned the MC4000/M198 around and easily pushed up and over the ramp to the causeway (Figures 47 through 49). Upon reaching the unprepared beach, the MC4000/M198 became hopelessly stuck (Figures 50 through 52). An LVTP-7 moved the M198 to hard ground, while the MC4000 extracted itself. Figure 53 shows the LST deck and ramp layout.

7 August. Because of a shipboard crane failure, evaluation aboard the LSD-34 was cancelled. Measurements conducted indicated that the M813 and MC4000 linked to the M198 would not have any difficulties maneuvering on the LSD flight deck.

8 August. The vehicles were loaded on landing craft and transported to an unprepared beach for a landing. The MC4000 easily loaded stowed and towed M198s onto an LCU (Figures 54 and 55) at the mud flats at NAB, Little Creek. The MC4000 demonstrated a very precise locating capability far beyond that of the M813. An M813/M198 loaded on an LCM-8 with offset barrel and split trails. After hookup and return of the barrel to towed position, the M813/M198 forded about 3 ft of water and became stuck at the edge of the unprepared beach (Figures 56 through 58).

Figure 47. MC4000/M198 Pushing Up Tank Ramp on LST-1196

Figure 48. MC4000/M198 Pushing Over Bow Ramp on LST-1196 to Causeway

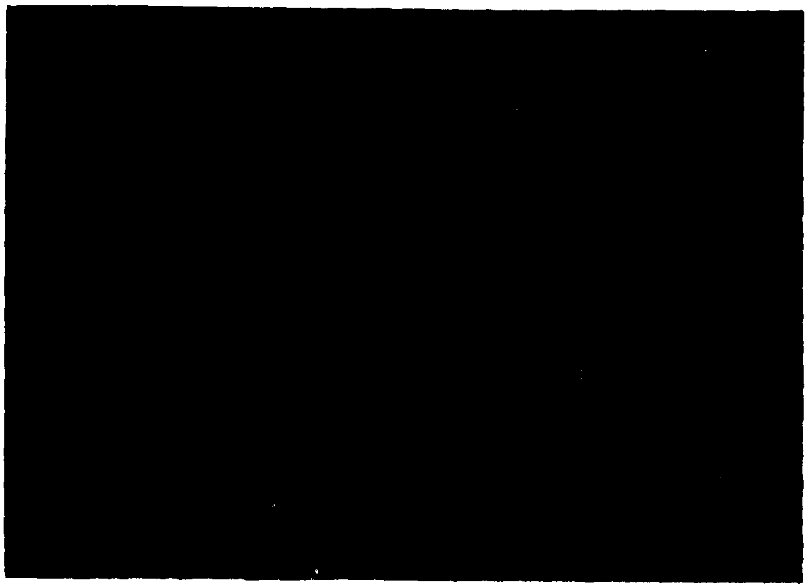

Figure 49. MC4000/M198 Pushing Across Causeway to Beach

Figure 50. MC4000 Pushing Stowed M198 onto Unprepared Beach from Causeway

Figure 51. M198 Stuck in Soft Beach Sand

Figure 52. MC4000 Stuck in Soft Beach Sand

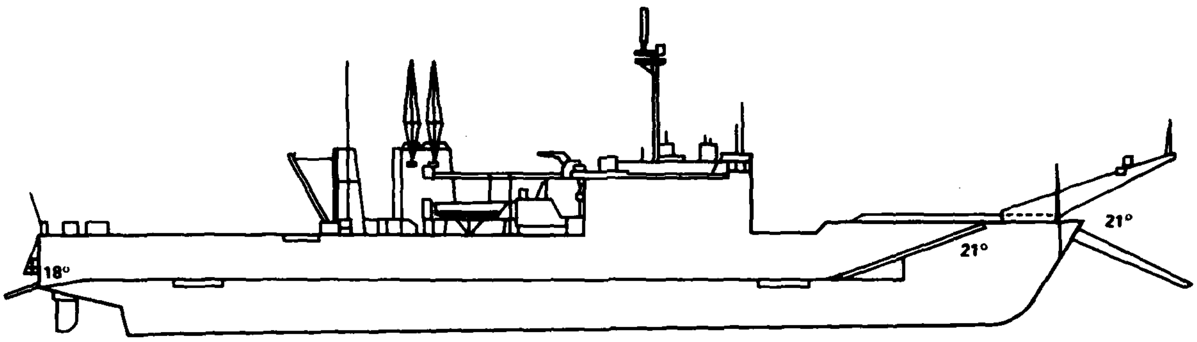

Figure 53. Profile of Tank Landing Ship (LST)

Figure 54. MC4000 Loading M198 in Stowed Condition on LCU

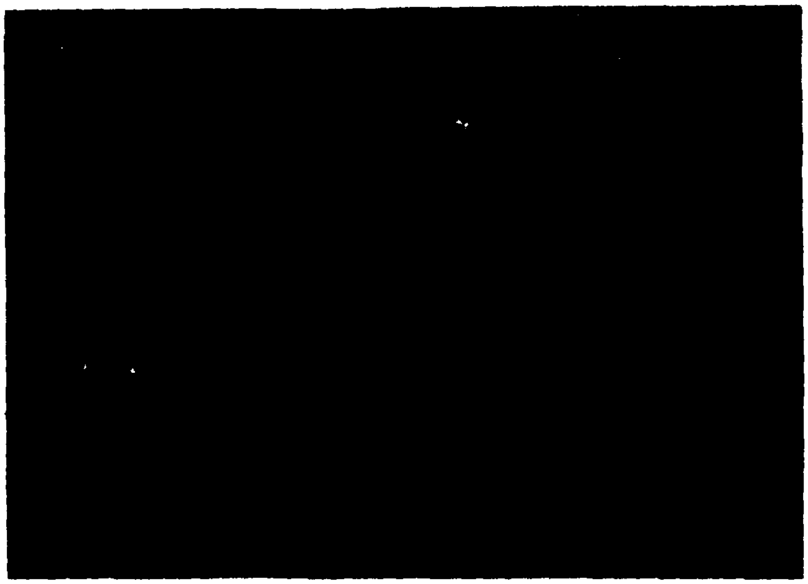

Figure 55. MC4000/M4K Loading M198 in Towed Condition on LCU

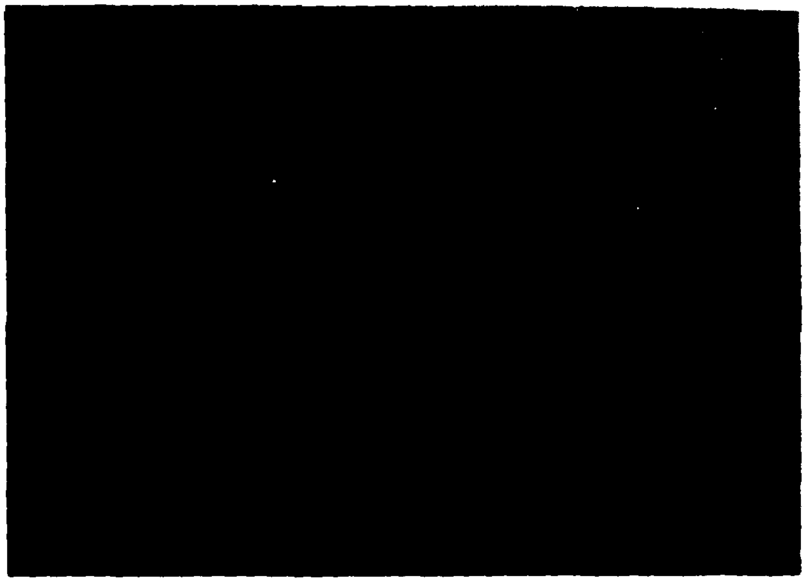

Figure 56. LCM-8 with M813/M198 Approaching Beach

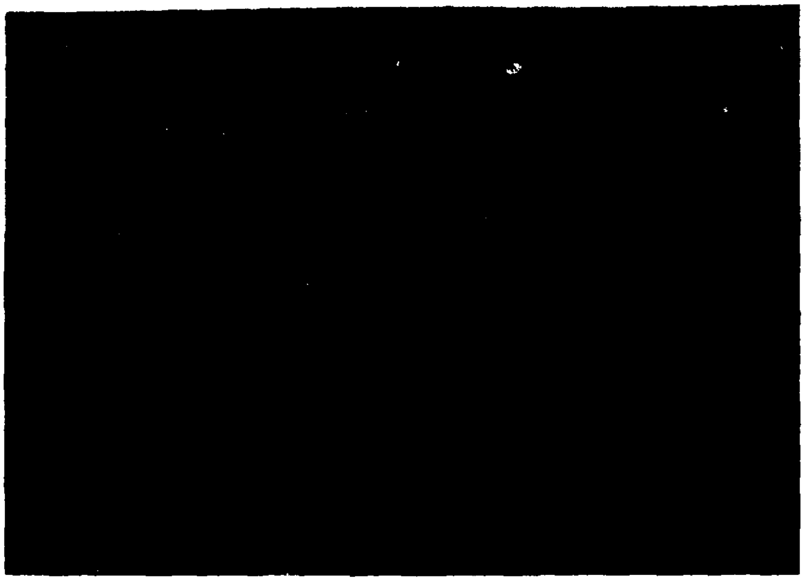

Figure 57. M813/M198 Fording to Beach from LCM-8

Figure 58. M813/M198 Stuck at Water's Edge on Unprepared Beach

The MC4000s debarked from the LCU, made their way to shore (Figure 59), and demonstrated the new winch system by pulling a passive MC4000 out of the water and over the beach (Figure 60).

Figure 59. MC4000s Debarking LCU

Test Summary

The PIP MC4000s performed beyond expectations and predictions of the performance studies. The brake, winch, and hitch systems performed as expected, but the maneuvering capabilities of the MC4000/M198 were much better than anticipated. The advantages of the MC4000 over the M813 are its

1. Short wheelbase articulated steering

2. Ability to lift the 3750-lb stowed M198 lunette load

3. Ability to adjust the M198 lunette height to correct for any ramp interferences

The MC4000/M198 combination provides all main ramp and deck maneuvering capabilities. It can maneuver all stern ramps and gates according to available gate size information and the MC4000 general ramp performance. The general ship capabilities for the MC4000/M198 are listed in Table 7.

Figure 60. MC4000 Demonstrating Winching Capabilities by Winching Passive MC4000 over Beach

The MC4000 proved superior in pushing rather than pulling the M198 up the various ramps. The pushing orientation allowed finer control of the M198 placement, provided superior visibility because the operator was loading forward, and provided better traction and power due to lower gear ratios and better weight distribution.

10TH MARINE FIELD EXERCISES

Following completion of the amphibious compatibility evaluation at Little Creek, the MC4000s were turned over to the 10th Marines for their field exercises at Fort Bragg, North Carolina. During these exercises, the two PIP forklifts were used for approximately 80 percent of all material handling (e.g., ammunition, crates) and provided the majority of all trailer and generator maneuvering. Twenty-five towed generators were handled several times by the forklifts for local mobility and on/off loading on low- and hi-boy trailers. The 10th Marine engineers were enthusiastic about the ease with which the forklifts handled the normally difficult, time-consuming loading procedures.

The MC4000s operated over a variety of terrain conditions (i.e., mud, sand, rock and semiflat hard-packed terrain), moving Army M198s and Marine Corps M101s several times with no difficulties.

Table 7. MC4000/M198 versus M813/M198 Amphibious Capabilities

Capability	MC4000/M198	M813/M198
Over Beach		
Wet sand	Good	Good
Packed sand	Good	Good
Dry soft sand	None	None
Crane Lift	Yes	Yes
Amphibious Ships (LHA, LPD, LST, LSD)		
Ramps	Good*	Good**
Stern gates	Yes†	Yes†
Side ports	LHA (only)	None
Flight decks	Good	Good
Turntables	Good	Poor
Landing Craft		
LCU	Good	Good
LCM-8	Good	Limited (unhooked)
General Maneuverability	Good	Good††

* Requires safety line on LPD 25° ramp.
** Trail ramp interference on LPD 25° ramp and landing craft ramps.
† Estimated from general ramp performance and measurements.
†† M813/M198 is restricted because of its excessive length (65 ft), (MC4000/M198--40 ft).

The power limitation problem that had occurred during the Little Creek evaluations was resolved during these field exercises. The 10th Marines felt that the vehicles had not operated at maximum capacity at Little Creek because the extensive storage period prior to the tests caused transmission slippage due to seal problems.

During the deployment of the 10th Marines to Fort Bragg, the two forklifts were worked 90 to 120 hr each. The following chargeable failures were noted:

1. The lower hoses on the PIP MC4000/old mast were snagged and broken four times on tree stumps, etc. The destruction of these hoses deadlines the vehicle.

2. The tilt cylinder hydraulic hose clamps (spot welded to mast) on a PIP MC4000/M4K broke loose on two occasions. As a result of this failure the hoses became tangled in the mechanism and were cut, deadlining the vehicle.

3. An MC4000/M4K lift chain failed due to a defective link pin.

The 10th Marines continued to operate the two forklifts at Camp Lejeune. As of April 1981, the vehicles had acquired 165 and 185 hr without major problems although several of the Fort Bragg problems had reoccurred. The lower hoses continued to be damaged and deadlined the MC4000 old mast version. The hose clamps on the MC4000/M4K mast continued to break after rewelding and resulted in more hose damage. The air compressor electrical system on both units failed; the vehicles had not been serviced until several weeks after the saltwater emersion at Little Creek. After subsequent cleaning of the control boxes, both units functioned as designed.

A weakness in the MC4000 electrical charging system was accentuated by the latest utilization of the PIP MC4000s. The increased usage of the vehicle in many areas of material handling and weapons and vehicle mobility created a large strain on the system. The vehicles under heavy use were started 10, 15, or more times a day instead of continually running; this placed a heavy load on the system batteries. A 60-amp output alternator powers the system and charges two 100-amp batteries. At the end of the day, the batteries are often weaker than at the start because of excessive starting and slow recharging rates. After one of the forklifts extracted itself from a mud bog with the PIP kit winch, there was insufficient electrical power to effect an engine restart. The batteries had to be removed and recharged.

A new hitch with tapers on the interference surfaces at the rear of the pintle hitch plate was manufactured at NSWC for the MC4000 old mast version to eliminate possible mast binding. Since reduction of the plate thickness was structurally impossible, a taper, top and bottom, would help the hitch cam over the mast upright crossbar on the MC4000 under heavy load situations. The new hitch was attached to the right fork located on the mast rail; a second MC4000 was used as the load. The fork carrying the hitch was used to lift the second vehicle by placing the fork tip under the lift post. The second truck was lifted 1 ft. At this point, the second fork truck's wheels were off the ground. The weight lifted was approximately 2000 lb, and the moment generated was equivalent to a 4000-lb load on the fork; no binding was noted. Examination of the MC4000/old mast revealed that the lower mast crossbar had been removed. The experiment was repeated with the forks of the second vehicle positioned on centerline as in PIP and the MC4000 PIP vehicle used as the load. The new hook cammed over the spanning plate from both top and bottom without incident.

SUMMARY

The PIP MC4000s performed beyond expectations and predictions of the performance studies. The vehicles provided the minimum capabilities required to improve local mobility for the M198. These capabilities have been convincingly demonstrated at Fort Bragg, Rock Island Arsenal, Camp Lejeune, and Little Creek.

The MC4000 has been helicopter-transportable since its inception. In the auxiliary mover role, it stows internally to a CH-53E while sling-lifting the M198 and ammunition, providing a total gun system insertion capability. The MC4000/M198 can maneuver over a variety of terrain conditions for a kilometer or more in the stowed or towed configuration; however, neither the MC4000/M198 nor the M813/M198 can negotiate very soft sand.

The PIP MC4000 provides greatly improved mobility aboard amphibious ships, landing craft, and transport aircraft. It can maneuver under the most extreme ramp configurations and greatly reduces or completely eliminates LST turntable evolutions, ramp interferences, and internal maneuverability problems.

The auxiliary air brake system performs as anticipated in the auxiliary mover role. Additional air volume may be necessary when the vehicle performs in high-utilization roles such as regimental mounting-out exercises. The winch system also functions well and is readily used for self-extraction.

The M4K mast system with its flexibility and the additional vehicular weight should enhance the overall capability of the forklift. The M4K mast system has no effect on the PIP kit except that it requires a slightly different pintle hitch.

It should be emphasized that the MC4000 auxiliary mover is considered an excellent solution to the mobility deficiencies of the M198. The vehicle has also proved itself in mounting-out evolutions, including the handling of heavy towed generators. The MC4000/M198 is stable, controllable, and quite capable of achieving the required local mobility.

RECOMMENDATIONS

The MC4000 auxiliary mover will perform as required with the designed PIP kits. For reliability rather than performance purposes, several minor modifications are necessary. These modifications are listed among the following recommendations:

1. At a minimum, PIP kits should be provided for the MC4000s attached to the artillery regiment.

2. Considering the usefulness of the vehicle in roles other than as M198 auxiliary mover, the entire MC4000 fleet should be fitted with the PIP kit.

3. The same concept should be considered for larger existing forklifts and for new RT forklifts to be adopted by the Marine Corps.

4. It is imperative that a skid plate be attached under the MC4000 mast to protect low-hanging hydraulic hoses from road hazards and obstacles.

5. In the event that M4K masts are adopted for service use on MC4000s, the hose fastener plates on the outer mast should be strengthened to prevent hydraulic hose damage.

6. To eliminate mast binding in certain load and vehicle geometries, the top edge of the MC4000 hitch rear attachment plate should be tapered in the same manner as the existing bottom edge taper.

7. The side walls on the MC4000 hitch should be stiffened.

8. The pintle hitch attachment pin should be increased in diameter and constructed of hardened steel.

9. The ball detent on the hitch attachment pin should be replaced with spring clip.

10. The electrical charging system performance should be improved with a larger alternator output or by modifying operational methods.

11. The volume of the brake system low-pressure warning buzzer should be increased.

12. Tine spacers for central positioning of the hitch tine on the MC4000 mast should be provided.

13. The problem of saltwater immersion of air brake system electrical controls should be considered.

14. The MC4000 should push instead of tow the M198 on ramps whenever possible to achieve better control, stability, and weight distribution and to utilize improved power ratios.

15. Other user roles for the auxiliary mover should be considered.

16. A larger volume air tank should be provided for roles other than that of M198 auxiliary mover.

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