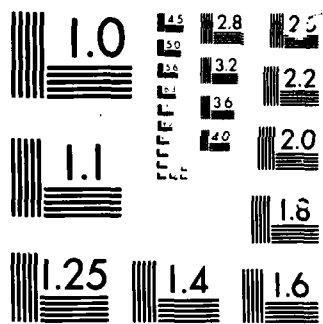


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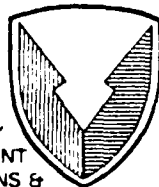
TECHNICAL REPORT ARFSD-TR-86002

IMPROVED PROCEDURE FOR LOADING THE
M198 TOWED HOWITZER ABOARD A C130 CARGO PLANE

ALBERT G. EBNER

APRIL 1986

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INTRODUCTION

This report covers an engineering study to improve a time-consuming and logistically unacceptable procedure for on/off loading of the M198 towed howitzer aboard a C130 cargo plane which severely impacts the howitzer's operational capabilities. The engineering study was treated in two phases: (1) development of an improved loading procedure, and (2) development of an improved jacking system and pintle assembly.

The principal objection to the original procedure centered on the fact that the wide tires on the howitzer did not fit between cargo rails added to the floor of the airplane. Since the rails could neither be removed nor tolerate the weight of the gun, a truckload of shoring was required to raise the wheels above the rails. The net effect was an air transportability procedure determined by the U.S. Army Forces Command (FORSCOM) to be unacceptable.

The main thrust of the study was dedicated to the development of a procedure to effect a significant reduction in on/off loading time and the elimination of shoring requirements. Of the more than 15 separately identifiable alternative loading procedures evaluated, a narrow tire approach emerged as the most satisfactory solution. The narrow tires reduced the gun's track to a width narrow enough to fit between the cargo rails, thereby eliminating the need for shoring and drastically cutting down on on/off loading time.

The narrow tire approach, as originally conceived, was specifically designed to alleviate the M198 air transportability problem and allow limited towing of the howitzer between an airhead and a position where the wide tires could be safely reinstalled. When not required, the narrow tires would be carried on brackets mounted on each side of the prime mover. Following exhaustive tests which conclusively demonstrated that the narrow wheels and tires performed as well as or better than the wide in all phases of operation, action was taken to remove the wide wheels and tires from the technical data package (TDP) and replace them with the narrow. This action obviated the need for the wheel mounting brackets and avoided a major logistics problem.

The second phase of the engineering study addressed the deficiencies of the original jacking and shoring procedure used for connecting and disconnecting the gun's lunette to and from the coupling-type pintle mounted on the front bumper of the 2 1/2-ton truck used in the loading operation. An improved, fast-acting jacking system, coupled with a fabricated front-bumper-mounted pintle assembly yielded results which essentially eliminated the logistics and time-related connect and disconnect problems.

Action in January 1985 to make the improved jacking system and pintle assembly kits available to all authorized units consummated a 4-year effort to improve the loading procedure.

DISCUSSION

The DA-approved material need for the M198 towed howitzer stated that the howitzer would be used frequently in airmobile operations and would require the capability of being transported by C130 or larger cargo planes for assault landings.

Records show that the howitzer was loaded without difficulty aboard a C130 cargo plane during its engineering development in the early 1970's. At that time, the cargo bay of the C130 accommodated the approximately 110 in. over the outside faces of the howitzer's wide tires without difficulty. However, sometime between 1970 and 1976, the Air Force added two 5-in.-high low altitude parachute extraction system (LAPES) rails, spaced at 105 in., to the ramp and cargo bay of the airplane. This incompatibility between the airplane and the howitzer was first manifested during the howitzer's operational testing (O.T. II) in June 1976. The Air Force stated that since the LAPES rails were made to be an integral part of the aircraft's superstructure, removal of any part of the rail system would render the aircraft unsafe for flying. The Air Force further stated that no load of any direction or magnitude acting on the rails could be tolerated.

The loading procedure developed during 1977 to compensate for the reduced floor width required 556 linear feet of 2 by 12 (actual size) rough shoring placed three high throughout the length of the ramps and cargo bay to raise the gun's tires high enough to clear the LAPES rails (fig. 1). An additional 160 linear feet of lumber was required for jacking and supporting the gun's trails while the gun was being separated from the truck which pushed it into the airplane and for supporting the trails during flight. The loading procedure is described in detail in reference 1.

Notwithstanding its many shortcomings, the procedure was considered for acceptance at an August 1976 General Officers' review, and at a subsequent Army Systems Acquisition Review Council (ASARC) II it was determined that the requirements for air transport of the M198 howitzer by the C130 cargo plane had been satisfied.

Neither correspondence nor other documentation yielded any data which suggested that logistics consideration had been given to the means by which the lumber supply would be maintained or to the many other critical considerations related to the procedure. Moreover, the procedure provided for no fallback position, i.e., if the lumber was not available, the gun simply could not have been transported by C130 aircraft. The possibility of having to leave the gun behind as a consequence of not having the lumber available was very real.

Later in 1977, in apparent acknowledgement of the procedure's numerous deficiencies, an alternative loading procedure was offered by the office of the Project Manager for Cannon Artillery Weapons Systems (CAWS) for Army and Air Force consideration. The procedure is described in Appendix A.

Early in 1980, the U.S. Army Defense Ammunition Center and School (USADACS) addressed proposals submitted by the Military Traffic Management Command (MTMC) as well as additional concepts proposed by USADACS in regard to the severity of the loading problem and the complexity of the concepts to resolve it, but there is no indication that any of their observations were seriously pursued. USADACS also addressed the desirability of a steerable third wheel attached to and supporting the gun trails to eliminate the need for a 2 1/2-ton truck in the loading operation. This proposal was motivated by the fact that the front axle weight of the 5-ton truck, with the weight of the gun acting on the front bumper, exceeds the load limits of the ramp on the C130. A steerable third wheel would permit the 5-ton truck to be used in the on/off loading operations.

Prompted by FORSCOM's determination in mid 1980 that the procedure cited in the transportation document and the Air Force-approved loading instructions¹ were unacceptable, cognizant representatives of the Army, Air Force, and Marines convened at Fort Bragg, North Carolina, to brainstorm alternative methods. A demonstration of the current loading procedure at Pope Air Force Base, North Carolina provided further insight into the problem. The meeting set the stage for the engineering study which developed the improved air transportability procedure that is the subject of this report. The study had as its cardinal objective the elimination of the truckload of shoring required to support the original loading procedure and the myriad of operational and logistically oriented problems associated with it.

ORIGINAL LOADING PROCEDURE

Description

While the shortcomings of using a truckload of shoring to overcome the interferences between the howitzer's wheels and the airplane's LAPES rails are obvious, FORSCOM's decision that the original loading procedure was unacceptable was based on the total scenario, which begins with a C130 cargo plane positioned on an assault landing strip, the cargo bay door down and in the ramp position, and the ramp extensions in place. The M198 howitzer in the towing configuration, with the gun's lunette connected to the rear pintle of the 5-ton truck, is positioned behind the airplane. After the crew disconnects the howitzer from the truck and the trails are lowered to the ground, the truck is moved away and the 2 1/2-ton loading truck is brought into position. While the crew holds the trails high enough for the pintle mounted on the front bumper to align with the gun's lunette, the truck moves forward and the connection is made. After the gun's travel lock has been disconnected from the bottom carriage and attached to the cradle, the top carriage is rotated approximately 180 degrees until the gun tube is in the stowed position and secured to the stowing bracket. The gun is now in

¹ Developed under Air Force Project 17-9-75.

the stowed configuration and ready for loading (fig. 2). With the possible exception of the pushing vehicle, such as the rough terrain military fork lift used by the Marines and/or other subtle differences, this portion of the loading operation is basic and common to both the original and the improved loading procedure.

As the gun is being prepared for the loading operation, approximately 556 linear feet of 2 by 12 (actual) rough shoring in lengths ranging from 4 to 10 feet are removed from a second truck (fig. 3) and positioned next to each of the LAPES rails throughout the length of the cargo bay, ramps, and ram extensions (fig. 4).

After checking to assure that projections on the 2 1/2-ton truck will clear the airplane's doorway and other readiness checks have been completed, the gun is pushed up the ramp into a pre-designated position in the airplane's cargo bay. The gun's handbrakes are set and the wheels chocked to prevent gun movement. This completes the first phase of the loading operation.

The second phase of the operation involves the separation of the gun from the truck. The method of jacking and supporting the trails for disconnecting the gun's lunette from the pintle mounted on the front bumper is shown in figure 5. This tedious, time-consuming, and comparatively dangerous operation requires two stacks of 2 by 12 rough shoring in 4-foot lengths and the 3-ton jack from the 5-ton truck. One stack of shoring is placed under the trail and a second positioned under the left spade bracket to support the jack. The stacks are built up as the jacking operation continues until the lunette is high enough to clear the pintle. The truck is then backed out of the airplane and the jack lowered until the trails are resting firmly on one stack of lumber. The gun is secured to the aircraft floor by chains, with turnbuckles to take up the slack. The gun is then ready for flight (fig. 6).

Wide Wheel and Tire

The wide wheel (fig. 7) is a special configuration available only from the Firestone Steel Products Company. The pronounced offset of the wheel rim, dictated by the howitzer design and clearance requirements (fig. 8), necessitated the reinforcing rings on each side to reduce the risk of damage and subsequent loss of inflation pressure in the radial tires.

The wide tire (fig. 9) was reportedly selected for its strength, stability, and flotation characteristics. Among its deficiencies, however, is its susceptibility to side wall damage during towing over rough terrain and the risk of loss of inflation pressure caused by side wall pressures breaking the bead. Also, tests conducted during this study showed that the 45-psi inflation pressure (permitted by the drawing) results in elevated tire temperatures when the gun is operated at the allowable 45 mph.

A significant shortcoming of the wide wheel and tire assembly is the extreme difficulty in mounting and dismounting the tire from the rim. Virtually impossible to accomplish manually, the tire changing procedure requires a special, difficult-to-operate machine which is seldom found in direct support maintenance shops.

IMPROVED LOADING PROCEDURE

Alternative Procedures Considered

During the period of October through December 1980, detailed consideration was given to approximately 15 concepts designed to eliminate the logistics, time, and cost-related problems associated with the original procedure for on/off loading the M198 howitzer aboard C130 cargo planes. To avoid the time and cost which might be invested in pursuing a concept considered destined to be a lost cause, the following general guidelines and constraints were established:

1. All ancillary equipment, such as shoring, jacks, pintles, etc., will be the responsibility of, and maintained by the gun crew.
2. No modifications to the cargo plane will be permitted.
3. No major redesign of the howitzer will be permitted.
4. The 2 1/2-ton truck will be used in all load/unload operations.
5. No load/unload procedure can depend on the availability and operational capability of a winching mechanism in the cargo plane.
6. Consideration for approval of any procedure is contingent upon strict adherence to all aircraft floor and ramp load limits.

The twelve alternative procedures selected for evaluation are given in table 1 and figure 10. Each concept was assigned a feasibility value based on engineering judgment, supplier input, and other pertinent information. In terms of time, cost, and other critical and practical considerations, the concept of using the aircraft pallets, some shoring, and a "bogey" wheel was originally perceived to offer the greatest potential for resolving the problem. The details of this concept were discussed at a meeting with Wright-Patterson AFB personnel and a decision made to test the procedure at Pope AFB. The planned scenario provided for an actual loading operation simulating the full spectrum of events which could be reasonably anticipated in a field environment during a phase II assault landing. Ironically, the narrow tire concept, identified as alternative procedure no. 2 was not considered to be a viable solution during this early phase and was, consequently, assigned a feasibility value of zero. The concepts of using dual wheels and removing the LAPES rails were also assigned poor feasibility ratings; dual wheels, because of a myriad of complex and costly design implications and rail removal, because of the Air Force's unalterable decision not to permit it.

Alternative Procedures Evaluated

Alternative No. 1

In terms of on/off loading time, troop exposure, logistical requirements, and other critical considerations, the original procedure (identified as alternative no. 1) is untenable by any standard.

Alternative No. 2

The prospect of using narrow tires and wheels as a means of reducing track width and, thereby, resolving the air transportability problem was originally considered to be out of the question. However, the thinking which suggested that the narrow tires would not support the load, would render the gun unstable, and would otherwise be unacceptable was not supported by test results. The narrow tire concept is detailed under Narrow Wheel and Tire Concept and in reference 2.

Alternative No. 3

The dual wheel approach (fig. 11) was considered highly desirable because it afforded a great deal of flexibility. The outer wheels could be removed to reduce the gun track enough to fit between the LAPES rails and reinstalled to provide the stability considered necessary (by some) to resist tipping. Research with wheel manufacturers, however, showed that the concept did not lend itself to the use of standard wheel elements. The outer wheel would require a very costly, highly offset, custom design unlikely to withstand the wear and tear of towing over rough terrain. The decision against the dual wheel concept was based principally on input from wheel experts who felt that it was impractical.

Alternative No. 4

Although perceived by many to be the simplest, most effective solution, removal of the LAPES rails to permit loading the gun without shoring was not really a legitimate alternative. There were strong indications at the inception of the study that the Air Force was adamantly opposed to the proposal for valid reasons; most notably, the prohibitive amount of time required to remove and later reinstall the large number of bolts which secure the rails to the airplane. Since the Air Force position was considered to have a reasonable basis, the concept was abandoned.

Alternative No. 5

An intuitive approach to alleviating the problem was to replace the wood shoring with other materials having the same gross dimensions. However, the benefits derived from using molded or extruded aluminum sections do not offset the other disadvantages associated with the basic shoring concept. The most that might be expected would be reduced handling and improved accountability. On the negative side, there would remain the problem of storage and availability, the risk of loss, and the need for special tapered sections to accommodate the transition from ground to ramp. Since no appreciable time savings were anticipated, the concept was not further developed.

Alternative No. 6

The concept of using an auxiliary "donut" tire over the wide tires to reduce the effective track of the gun (fig. 12) was introduced at the brainstorming session at Fort Bragg in September 1980. Encouraged by research which revealed that Goodyear Tire and Rubber Company was developing such a tire for the farm industry, the concept was reviewed as a potentially viable solution and actively pursued. The method of application would call for the donuts to be carried in the bed of the 5-ton truck (prime mover) for immediate availability when airlifting the gun by a C130 airplane. As part of the preparation for gun loading, the wheels would be raised to the "full up" position. The donut would be positioned to the inboard side of the wide tire so that the distance over the outside faces would be comfortably less than the 105 in. between the LAPES rails, and then inflated to approximately 100 psi. After the wheels were lowered and locked in position, the gun would be ready for loading onto the airplane without shoring.

Several negative considerations influenced a decision to abandon the donut tire development. Further research revealed that the design concept was not fully established and that the development cost would probably be prohibitive. Since the two donuts, side by side, would be more than 4 1/2 feet in diameter, more than 20 in. in width, and probably weigh more than 100 pounds, they would pose unacceptable storage and handling problems. Although the donut would have treads on both the inside and outside diameters, it is doubtful they would resist the tendency toward shifting on the wide tire as the gun is being steered into the airplane.

Alternative No. 7

Although not considered suitable for development, one proposal provided for the use of telescoping or pivoting legs connected to and stowable on the howitzer frame. Attached to the ski-type feet of the legs would be pads of ultra high molecular weight (UHMW) polystyrene having a very low coefficient of friction. During the loading operation, the legs would be lowered to contact and

ride on the aircraft rollers. The concept left to the imagination of the developer such things as the design and placement of the legs and the manner in which the gun would be moved from its place on the ground to a position in the airplane where it could be easily pushed along the rollers. While the concept works effectively in the loading of square or rectangular shaped vans, it does not lend itself to the comparatively complex configuration of the M198 howitzer. Not only was the development of this concept envisioned as very costly, it is doubtful that it would effect a meaningful reduction in loading time. Furthermore, it would require an intolerable increase in howitzer weight and pose serious logistics problems. It was therefore abandoned.

Alternative No. 8

Initially considered to offer the simplest, fastest, most economical solution, this alternative proved to have little merit. It was based principally on the premise that the Air Force would approve loading the gun in the towing configuration, in which case the 5-ton truck could be used. While there were other negative aspects of lesser consequence, such as procedural complexity, it was the Air Force's objection to the towing configuration which was the deciding factor to abandon the concept.

Alternative No. 9

The "dolly under the carriage" concept posed enormous design, application, and logistics problems. The device would require a frame of substantial size and strength; large diameter, wide tires to support the load; some method for getting it under the bottom carriage, and other negative considerations. The logistics problem of storage constituted sufficient cause, in itself, to consider the concept unsuitable for development.

Alternative No. 10

The "bogey" wheel distinguished this alternative as a potential candidate to solve the air transportability problem. However, it was not only the abandonment of the bogey wheel which decided the case against development efforts. The procedural complexity and other negative aspects also contributed to the decision that the concept did not warrant further study. As it turned out, the bogey wheel played only a minor role in the alternative procedure and the jack did not bear at all on the loading operation except for its use in disconnecting the gun from the truck. Had the narrow tire concept not worked out satisfactorily, this approach might have been adopted as the most reasonable alternative to the original loading procedure. Notwithstanding its numerous shortcomings and less than significant time savings, it was recommended for serious consideration by the Air Force. Although it is doubtful the Army would have been in enthusiastic endorsement of this approach, it did offer improvement and eliminate much of the shoring requirements.

Alternative No. 11

Offered by the troops during the very early phase of the study, the concept of using an ammunition trailer to support the trails during the loading operation was not given very serious consideration, even though, in the sense that the trailer would have served as a bogey wheel, it offered some early appeal. It became quickly evident, however, that the implied improvisation was not so simple and that the trailer would require extensive modifications to accommodate its interface with the gun. Under the best circumstances the concept did not offer any apparent tangible benefits and was not pursued.

Alternative No. 12

The retractable wheel alternative was offered for consideration by personnel at Wright-Patterson AFB. The theory behind the concept was considered sound because it provided for quick emplacement of secondary wheels to fit between the LAPES rails. However, in view of the anticipated costly and complex design, the increase in gun weight, possible interference with functional features of the gun, and other negative aspects, the concept was not considered suitable for development.

The challenging nature of the air transportability problem evoked suggestions from many civilian and military quarters. In the interest of avoiding time, cost, and effort, concepts which were considered to show little promise of acceptance after preliminary study were not pursued.

Bogey Wheel Developed and Abandoned

One of the challenges presented at the September 1980 meeting at Fort Bragg was the development of some means by which the 5-ton truck could be used in the loading operation.

In consideration of the fact that the front axle weight of the 5-ton truck, in combination with the weight of the gun trails, exceeds aircraft ramp load limits, it is not considered a viable alternative to the 2 1/2-ton truck for the on/off loading operation.

Unfortunately, the compact, strong, and highly maneuverable case MC4000 rough terrain military forklift used so effectively by the Marines in their loading procedure is not part of the Army Table of Organization and Equipment (TO&E).

Sometimes referred to as the "Case Loader," the MC4000 (figs. 13 and 14) has been effectively used by the Marines as an integral part of their loading procedure and reportedly permits fast loading of the gun without the need for jacking and shoring to separate the gun and support the trails. The forklift's powerful

diesel engine, power steering, tight-turning capability, automatic transmission, and high degree of maneuverability in all axes permit the truck to easily push the gun up the airplane ramp. After positioning the gun in the cargo plane bay, the trails are supported on a pedestal for flight. Previously unsuccessful attempts to have the MC400 added to the TO&E were reportedly attributed to funding constraints and a perceived problem in transporting the loader during convoy movement. However, with regard to cost, a Case representative stated that a loader equipped for our application would cost less than \$40K.² Also, while the manufacturer recommends that the loader be made free-wheeling and towed for long distance travel at highway speeds, the Marines tow the M198 howitzer at speeds up to 20 mph.

The deficiencies of the 2 1/2-ton truck are strongly manifested during the on/off loading of the M198 howitzer, especially when using the shoring procedure. Of approximate equal weight and concern are the steering, clutching, and power problems. The truck is simply not strong enough to effectively push the gun over the stepped shoring, up the airplane ramp, and into position in the cargo bay. Although the steering problems would be marginally alleviated by additional power, the absence of power steering makes maneuvering the gun and truck over the shoring extremely difficult. The problems are aggravated by the fact that the truck does not have an automatic transmission and, consequently, does not have the "creeping" capability necessary for inching the gun into position to effect connection/disconnection of the gun to/from the truck.

Several Air Force representatives and others in attendance at the September 1980 meeting strongly advocated the use of a bogey wheel attached to and supporting the gun trails to permit using the 5-ton truck in the loading procedure.

The obvious need for a stronger vehicle for the loading operation was dramatized during the demonstration which followed the meeting at Fort Bragg. Motivated by what was perceived to be a strong need for such a device, work was begun to develop a bogey wheel which could be quickly and easily attached to and removed from the trails. The design concept (fig. 15) consists of two commercial swiveling casters with pneumatic tires attached to a foldable aluminum weldment frame. The simple, virtually maintenance-free structure was designed to be secured to the trails by means of the spade lugs used to secure the spades to the trails. The tongue of the bogey wheel, used to connect to the pintle mounted on the front bumper of the 5-ton truck moves up and down through an angle of approximately 15 degrees to compensate for changes in the angle of the truck with respect to the gun as the gun is pushed up the ramp and into the airplane. Among its advantages was the fact that it eliminated the need for jacking and shoring to separate the gun from the truck.

The package was designed to weigh approximately 300 pounds and fit conveniently in the bed of the primer mover.

The completed, Air Force-approved design was ready for prototype fabrication when the concept was abandoned by direction of Fort Sill in 1981. The decision

² All cost estimates were made in 1985.

was based on the lack of available storage space in the 5-ton truck and the bogey wheel's limited utility.

Although the drawing package reflects only a prototype approach, the design is considered sound and functional. With the advent of the narrow tires and wheels and the elimination of shoring, the bogey wheel would lend itself well to the new procedure.

Narrow Wheel and Tire Concept

In the course of developing the narrow tire concept, numerous contacts were made with representatives of the tire and wheel industries to explore the possibility of finding a narrow tire/wheel combination capable of satisfying demanding clearance and configuration constraints, and strong enough to support the required load. The objectives called for a reduction in howitzer track to fit between the LAPES rails and capability of supporting the gun for slow speed towing over short distances. The package would be designed for specific application to air transport of the M198 howitzer in a C130 cargo plane. During normal towing and in other operational modes, the gun would be equipped with the wide tires and wheels. With these goals in mind, full thrust was given to the development of a narrow tire and wheel package.

Development demanded close coordination with personnel at Wright-Patterson and Pope AFBs and a knowledge of the floor load limits and other constraints relative to the C130 to insure that all Air Force requirements would be met. Static loads on the aircraft floor and ramp areas must be limited to 50 psi, a critical consideration in any concept evaluation process (ref 3). However, the 50 psi restriction is not applicable to pneumatic tires with less than 100 psi inflation, provided the axle weight does not exceed 13,000 pounds (6,500 pounds per wheel) and the distance between wheels is at least 30 in. The narrow tire approach fell well within these parameters.

Also critical to the development and evaluation process was the availability of accurate data relative to the various features of the howitzer in terms of size and weight as they interface with the airplane. Gun weight data generated at Rock Island Arsenal and other government and contractor's facilities revealed disparities which suggested the advisability of developing more reliable information. Personnel at Aberdeen Proving Ground (APG) determined that the average total weight of several recently produced howitzers was 15,600 pounds. With the gun in the stowed configuration required for aircraft loading, the average weight at the pintle was 3,730 pounds. Based on these figures, it was determined that the average axle weight was 11,870 pounds or 5,935 pounds on each wheel.

Based on the gun weight information provided to Firestone Tire and Rubber Company and Standard Wheel and Rim Company, a package consisting of a 10:00-20 g-load rated (14 ply) radial tire with highway tread, mounted on a 7.5-in. three-piece steel rim was selected to satisfy requirements (ref 4). Calculations showed that such a package would reduce the measurement over the outside face of the howitzer tires from approximately 111 in. to 99 in., permitting the gun to fit easily between the LAPES rails spaced at 105 in. (fig. 16).

The decision to use a radial tire in the initial approach was strongly influenced by the fact that the original tires on the M198 were radials. However, the radial tire was later re-evaluated and replaced by a bias ply tire with tube and flap, which lowered the cost and reduced susceptibility to sidewall damage during cross-country towing. The disadvantages of the bias ply tire's shorter tread life and increased potential for heat build-up were ameliorated by such application-oriented considerations as tolerance for off-road abuse and resistance to loss of inflation pressure caused by sidewall pressure, as is often the case with radial tires. Also, while the radial tire is reportedly good for approximately 50,000 miles of highway towing, the somewhat lesser projected life expectancy for the bias ply tire more than satisfies the approximately 3,000-mile requirement stated in the material need.

In addition to the major concern of selecting a tire capable of supporting the approximately 6,000 lb which would be imposed on it, the configuration of the narrow wheel was also a matter of concern. The selection was predicated on the availability of a standard wheel having a configuration in which the inner portion favorably complemented the configuration of the brakehead assembly. The selected wheel easily satisfied the requirements.

Throughout the narrow tire and wheel concept development, close communication was maintained with artillery-wise representatives of using units at Fort Bragg to insure that all basic and critical requirements and considerations were addressed and satisfied. The officers and troops provided invaluable guidance and support during the entire development effort.

Description of Narrow Wheel and Tire

The narrow wheel described in the source control drawing (fig. 17) was selected for its strength and configuration, as well as a construction which allows positioning of the disc within the rim to accommodate critical clearance requirements. The drawing depicts a rim produced by Firestone Steel Products Company, which is the only narrow rim currently qualified to satisfy existing requirements. Its three-piece design (fig. 18) permits comparatively easy tire changing, even in the field, with readily available standard tools. The wheel assembly is typical of the multi-piece rims which have been successfully used for many years on military vehicles, such as the 2 1/2- and 5-ton trucks, and throughout the commercial trucking industry. The companies identified as approved sources on the drawing provided the material used in all qualification tests. Approval of additional sources would require testing by the U.S. Army Armament Research and Development Center (ARDC).

The narrow tire described in the specification control drawing (fig. 19) is a bias ply construction in popular usage in the commercial trucking business. Although the drawing references Goodyear and Firestone as suggested sources of supply, a tire meeting all indicated specifications is widely available from other sources through Army supply channels by national stock number (NSN). Complementing the narrow tire is a standard tube and flap, also available by NSNs.

The narrow wheel and tire assembly (fig. 20) weighs approximately 233 lb; at least 33 lb lighter than its wide counterpart, yielding a reduction in howitzer weight of more than 65 lb. The total cost represents a significant savings over the cost of the wide wheel and tire unit. A comparison of the narrow and wide wheel and tire assemblies is illustrated in figure 21.

Air Transportability of Narrow Tire Concept

Satisfied that layouts, weight and dimension checks, manufacturers input, and other data validated the soundness of the concept, arrangements were made to test the on/off loading of the M198 howitzer equipped with narrow wheels and tires on a C130 cargo plane.

Through the coordinated efforts of the Firestone Tire and Rubber Company and Standard Wheel and Rim Company, a set of tire and wheel assemblies was made available on loan for testing and prove-out. The units were assembled to a recently produced howitzer at Fort Bragg, and measurements taken to verify that the narrow wheels and tires effected the necessary reduction in track to permit the gun to fit comfortably between the airplane's LAPES rails.

Under the coordination of the Systems Management Office of the U.S. Army Armament, Munitions and Chemical Command (AMCCOM), plans were finalized for a test loading at Pope AFB in July 1981. The test was accomplished by the 1st Battalion, 73 Field Artillery, B Battery, Fort Bragg. Representatives from cognizant offices of Fort Bragg, Pope AFB, and Wright-Patterson AFB as well as from several other interested agencies participated in the test program.

The on/off loading operation was performed without incident, offering convincing evidence that the narrow wheels and tires provided the long sought relief to the M198/C130 air transportability problem. The test conclusively demonstrated that not only could the gun equipped with narrow tires be pushed into and pulled out of the airplane quickly and easily, but also in less than one-fourth as much time as required by the wide tire shoring procedure. Connection and disconnection of the gun to and from the truck was accomplished in accordance with the established procedure prescribed in reference 3.

Based on the favorable test results, the USAF Airlift Center (Pope AFB) recommended that, "The M198 Howitzer with narrow tires should be certified for transportability aboard the C130 (equipped with A/A32H-4A dual rail system) and C141 aircraft (OPR: HQ ASD/ENEC)." The final report (ref 5) concluded that there are no safety considerations unique to loading/unloading the M198 Howitzer with narrow tires and that no rolling shoring is required to position the M198 in the aircraft. The improved loading procedure was subsequently approved by the responsible segments at Wright-Patterson AFB and Headquarters for the Military Air Command at Scott AFB, Illinois.

Limited Towing and Handling Characteristics Test

The impressive outcome of the narrow wheel and tire concept test conducted at Pope AFB in July 1981 provided the basis for a decision to move forward, without delay, in the development of a narrow wheel and tire package to accommodate the new loading procedure.

The original scenario, as it applied to the use of narrow wheels and tires, was one in which the conversion would take place at an airhead immediately prior to loading. However, when it was realized that this concept fell far short of users' needs, it was expanded to provide for a more realistic situation; one in which the wheels and tires would have the capacity of being towed over variable terrain to a position up to 25 km from the loading point. At some safe distance or treeline, the wide wheels and tires would be removed and the narrow wheels and tires assembled to the gun. Wheel brackets (fig. 22) were designed to be secured to the right and left sides of the truck body for stowing the narrow wheel and tire assemblies when they were not being used in an airlift operation. Although the brackets were designed to accommodate the wide wheels as well, it is more likely the wide wheel and tire assemblies would have been carried in the bed of the prime mover and transferred to the airplane to assure their availability on arrival at destination.

Using the 25-km requirement as a cornerstone of criteria, a Test Program Request (TPR LCW-A-2618) was structured to evaluate the towing capabilities and handling characteristics of the M198 howitzer equipped with narrow wheel and tire assemblies. The program also addressed the wheel mounting bracket for fit and function and certification of the tire's g-load capabilities to satisfy airplane floor loading limitations. The test program gaged the performance of the narrow wheel and tire assemblies against the wide tires and wheels through a broad spectrum of critical considerations. The entire test was conducted at Aberdeen Proving Ground, Maryland, under the direction of the Materiel Testing Directorate in accordance with TECOM Project No. 2-WE-200-198-038. Details of the special study test results and analysis are outlined in reference 6.

In deference to the urgency expressed by higher command to publish test results on a phase-by-phase basis as soon as they became available, a system providing for the incremental release of test data by teletype communication was established.

The first phase of the test addressed the critical Air Force requirement concerning the capability of the narrow wheels and tires to withstand a load of 4.5 g's for a minimum of 0.1 sec. High speed photography was used to record the test which showed the assemblies withstood the 4.5-g load for 0.22 sec, more than twice as long as required, with no evidence of damage to the wheels or tires. One of the major concerns of the engineering community addressed during the second phase of the test was the probable forfeiture of the howitzer's stability in consequence of the reduced track of the gun with the narrow tires. Although testing criteria for side slopes have included only up to 30%, the howitzer safely negotiated a 40% slope with no evidence of tipping. Even though the APG report made no reference to the influence of the narrow tires on braking distances and turning diameters, an ARRADCOM representative monitoring the test reported that the narrow wheels and tires also effected improvement in these areas.

Instrumented towing was completed over secondary roads, Belgian block, and cross country courses with no evidence of the weapon becoming unstable at any time, nor its 6-g design limit being exceeded. The gun, equipped with narrow tires, was also towed over paved roads and through sand and mud courses. Again, although not expected to do as well in mud as its wide-tired counterpart, the howitzer pulled more easily without the plowing effect in evidence with the wide tires. This benefit was attributed, at least in part, to the in-line tracking of the narrow tires with the rear (dual) wheels of the prime mover.

Another critical area of concern to the engineering community and, therefore, a cardinal feature of the test program, was the ability of the narrow tires to remain within prescribed temperature limits during towing at high speeds over improved, paved roads. The maximum temperature at which a bias ply tire can successfully operate is 250°F (121°C), according to reference 7. The test operating procedure (TOP) further states that these temperatures refer to the "hot-spot" in the tire, normally the thickest portion of the tread shoulder at a depth close to the carcass. The APG document also states that the tire carcass temperatures are obtained by stopping the vehicle and inserting a needle thermocouple into holes drilled at predetermined points in the tread of the tire. This is exactly the same procedure for measuring tire temperature used by the Firestone Tire and Rubber Company and other major tire manufacturers. Although Goodyear uses a somewhat different method of measurement (ref 8), the 250°F limit applies.

Following one hour of towing over paved roads at 50 mph (80 km/hr), considered to be the worst case, the maximum carcass temperature of the narrow tire was 233°F (112°C). After an additional two hours of towing at the same speed, the temperature appeared to have stabilized at 243°F, the highest temperature attained by the narrow tires during worst condition towing at 50 mph. However, according to the report, based on this testing a towing limitation of 40 mph (64 km/hr) was recommended. The APG report also stated that tire carcass temperatures in excess of 250°F (121°C) are anticipated with the narrow tires over high-speed paved road surfaces at towing speeds greater than 40 mph (64 km/hr). See the results of the narrow tire temperature tests in figure 23.

During each element of testing, the performance of the narrow wheels and tires at least equalled, and in many cases was measurably better, than that of the wide wheels and tires. Based upon the test's satisfactory outcome, an engineering change proposal (ECP) was prepared to replace the wide tires/wheels with narrow tires/wheels. The proposal included suggested input to manuals, assembly and mounting instructions, and detailed restrictions for usage. The most notable restrictions were a speed limit of 40 mph maximum (continuous) over improved roads, and a limitation of 300 miles over variable terrain. These and other operational constraints were later reevaluated at the request of AMCCOM to determine the acceptability of their elimination. The AMCCOM request cited the favorable results of the environmental testing conducted at APG and the User Concept Evaluation Tests conducted at Fort Bragg, and recommended that consideration be given to rescission of the 40 mph and the 300 mile distance limits and other usage limitations. Following an in-depth reevaluation of test reports and other available data by ARDC, action was taken to remove the restrictions and allow the narrow wheels and tires to be operated under the same relative conditions as the wide wheels and tires, i.e., 45 mph maximum, etc.

Independent Design and Producibility Assessment Reviews

In accordance with regulations governing the conduct of an Independent Design Review (IDR) and Producibility Assessment Review (PAR), data reflecting the details of the narrow wheel and tire design and test related data were provided to the chairman of each review team.

Composed of personnel possessing a demonstrated knowledge of weapon system design and performance requirements, the IDR team conducted a detailed evaluation of each element of the proposed concept. Members of the team witnessed the towing and handling characteristics tests at APG and identified concerns which they considered warranted additional testing and/or design modification to insure that performance requirements would be satisfied. Five of the seven areas of concern recommended that tests be conducted or measurements taken after completion of the test program to verify that the gun incurred no damage attributable to the narrow wheels and tires. One concern addressed the split ring of the three-piece wheel and another proposed repositioning the tire stowing brackets to improve the driver's rear field of vision. After each concern was evaluated and dispositioned to the satisfaction of the IDR team, the concept was approved for release.

Since there are no producibility considerations related to the commercial wheels and tires, the PAR team concentrated its attention on the design of the wheel stowing bracket. The basic bracket design was a steel weldment which allowed the bracket to be easily hung on the side of the body of the truck and secured by two hook bolts. Three studs were welded to the bracket for securing the wheel. However, the PAR team proposed a threaded clamping feature with a handwheel instead of the studs and lugnuts to make the hanging and removal of the wheel faster and simpler. As a result, one bracket reflecting each configuration was fabricated and subjected to tests which yielded results indicating the troops' preference for the PAR team design.³

Wheel and Tire Endurance Testing

The satisfactory outcome of the mobility and limited towing tests completed at APG in October 1982, complemented by the results of the User Concept Evaluation Tests completed at Fort Bragg and Pope AFB in early December 1982, prompted the U.S. Army Armament Research and Readiness Command (ARRCOM) to direct the preparation of a Product Improvement Program (PIP) to address full fleet, permanent replacement of the M198 howitzer's wide wheels/tires with narrow wheels/tires. In spite of the time and funding-related problems inherent in the approach, the PIP was viewed as the only administrative vehicle suitable for evaluating the acceptability of the narrow wheels and tires for conversion.

³ As indicated elsewhere in this report, permanent replacement of the wide wheels and tires obviated the need for the wheel mounting brackets.

In January 1983 the U.S. Army Field Artillery School (USAFS) informed ARRCOM that emerging results of the recently conducted Concept Evaluation Tests, "... indicate that the narrow tire/wheel concept is viable both to facilitate C130 loading and as a permanent replacement for the wide tires and wheels." The USAFS stated that it was the user's formal position that the narrow tires/wheels offer potential advantages in towing characteristics, repairability, and availability and that the narrow tires/wheels should permanently replace the wide tires and wheels as soon as possible. The user's formal position also called for the development of a standard front bumper-mounted pintle and an improved jacking system, to be issued as a kit, to facilitate the separation of the gun from the truck in the aircraft loading operation. The development and issue of the kit should be a separate action from the fielding of the narrow tires and wheels.

In deference to the user's stated position and expressed urgency, ARRCOM's engineering management directed the abandonment of the PIP approach and requested that the engineering study (ES 1A-7-8396) be expanded to include narrow wheel/tire endurance testing and the development of an improved jacking system and pintle assembly kit. This simpler, far more expedient approach provided for the issuance of an ECP to accommodate full fleet conversion to the narrow wheels and tires and the obsolescence of the wide wheels and tires upon satisfactory completion of the endurance test program.

The stated objective of the test program request (TPR-LCW-A-2732) forwarded to APG in late January 1983 was to evaluate the ability of the M198 equipped with narrow wheels and tires to satisfy original performance criteria, i.e., to be capable of operating over unimproved roads and to have cross-country mobility greater than or equal to that of the towed medium, field artillery weapon, e.g., the 155-mm towed howitzer M114A1.⁴ The test program identified long term endurance and wear as critical elements of concern. It also referenced the fact that these special study tests were an expansion of the limited towing tests conducted at APG during August and September 1983 under TPR LCW-A-2681. Those tests demonstrated the capability of satisfying all critical performance requirements, but did not address the durability of the narrow wheels and tires to withstand the rigors of high-speed towing over paved roads and long-distance towing over variable terrain.

The test program provided for a set of new wheel and tire assemblies to be mounted on a recently produced M198 howitzer and subjected to 3000 miles of temperature-monitored and instrumented towing at various speeds over various terrain. The gun would be towed for a specified number of miles over primary and secondary road courses, cross country, etc., apportioned as prescribed by the operations mode summary for the M198 howitzer, as well as comparative narrow and wide tire towing tests over various grades of mountain roads. Particular attention would be given to tire temperatures and wear and any indication of damage to wheel or tire throughout the test program.

The Churchill test area course A at APG is the most hilly of the cross country courses, characterized by rocky terrain, ravines, steep grades up to 30%, and

⁴ Paragraph VI.C(2)(a) of the Material Need (MN).

side slopes. The howitzer equipped with narrow wheels and tires traversed the course easily and smoothly, with no evidence of degradation of the handling characteristics displayed by the gun equipped with wide wheels and tires.

The test report (ref 9) stated that during a 4-hour run of the gun equipped with narrow tires at speeds of 45 to 50 mph (72 to 81 km/hr) and ambient temperatures of 80° to 94°F (27° to 34°C), the highest temperature measured was 229°F (109°C). However, during a 4-hour run of the gun equipped with wide tires at a slower speed of approximately 40 mph (64 km/hr) and lower ambient temperatures of 80° to 86°F (27° to 30° C), temperatures above 250°F (121°C) were measured after only the second hour of operation. After 4-hours of towing the temperature was measured at 265°F (129°C) and still rising. The report recommended (1) that the wide tires be operated at a higher inflation pressure, or (2) that a speed limitation be established and set for the wide tire when operating at the customary inflation pressure of 45 psi.

At 1,703 mi (2,741 km) of towing, tread depth measurements taken on the narrow tires showed an average wear of 0.52 in. (13 mm). The tread depth indicates a potential tread life of approximately 15,000 mi (24,140 km). In contrast, the average tread wear for the wide tires during the comparison test conducted under TECOM Project No. 2-WE-200-198-034, after travelling only 1,219 mi (1,962 km) over similar road surfaces was 0.7 in. (18 mm), nearly twice the wear rate of the narrow tires.

The narrow tires were used for a 3,000 mi (4,828 km) endurance phase in the form of 100 mi (161 km) missions (24 km paved, 105 km secondary, and 32 km cross country, with every fifth mission being severe cross country), in addition to the hilly cross country towing to determine handling characteristics.

The following conclusions are drawn in the test report (ref 9):

1. The narrow tires met or exceeded all performances exhibited by the wide tires in each phase of the test.
2. There was no degradation in handling characteristics of the M198 howitzer equipped with narrow tires.
3. The carcass of the wide tire exhibits a higher temperature than that of the narrow tire when towed under the same conditions at the operating inflation pressure for each tire.
4. The physical performance and condition of the howitzer was not degraded as a result of towing operations performed with the narrow tires, compared with results of previous testing of the M198 howitzer equipped with wide tires.

User Concept Evaluation Tests

During November and December of 1982, six M198 howitzers alternately equipped with narrow and wide wheel and tire assemblies were subjected to environmental, troop-oriented testing at Fort Bragg and Pope AFB in accordance with a

Concept Evaluation Test Proposal (CEP) directed by the USAFS, Fort Sill. The tests were conducted under the direction of the U.S. Army Airborne Board with the support of the 18th Field Artillery Battalion troops, equipment, and supplies. The CEP was identified as TRADOC TRMSM 83-CEP-113 and USAABNBD Project No. 2C024. The test scenario included convoy towing over approximately 500 miles of variable terrain, tire changing, before/during/after inspection of howitzers and tires, use of wheel mounting brackets, and static loading and fly-out aboard a C130 cargo plane. Detailed data collection forms issued to each member of the six gun crews solicited subjective/factual observations with regard to the towing characteristics and other factors bearing on the comparison testing.

The test plan was adjusted, as circumstances suggested or dictated, to optimize the value of the concept evaluation. Extensive video and still camera coverage was used to record each element of the test scenario for later analysis, evaluation, and record. Times and conditions were diligently annotated by data collectors to insure a faithful and accurate record of events for use in data collection.

Riding alternately in the back and cab of the 5-ton truck (prime mover) during towing over the 53-mile variable terrain course afforded an opportunity to make first hand observations and discuss the performance of the gun with the truck driver and other members of the gun crew. Based on troop and test director comments, as well as personal observations, it was concluded that the gun with narrow tires performed as well as, and in many instances superior to, the gun with wide tires.

The wheel mounting brackets which accommodate the wheels when not in use performed satisfactorily and showed no evidence of damage, but their position on the sides of the truck restricted visual access to the gun through the rear view mirrors mounted on the sides of the cab.

The summary of troop responses to the mobility comparison data forms (app B) testifies to an overwhelming troop acceptance of the narrow wheel and tire concept. The survey reflects the opinions of at least six drivers and more than 50 crew members having an extensive background of field experience with the M198 howitzer.

The CEP report (ref 10) recommended that "... due to the satisfactory performance of the narrow wheels/tires during mobility operations, consideration should be given to a permanent replacement of the wide wheels/tires with narrow wheels/tires on the M198 howitzer." The suggestion pointed out that such an equipment modification would negate the requirement to maintain an additional set of wheels/tires for airload contingencies, along with the need to provide wheel-carrying brackets.

Although the acceptability and benefits of using the narrow wheels/tires had already been established and the Air Force had given its approval of the concepts, the CEP called for a test loading and flyout to satisfy the Army's concept suitability requirements.

Based on a series of test on/off loadings, it was determined that the time required to load the M198 configured with narrow wheels/tires aboard a C130

ranged from a low of 6 minutes, 43 seconds to a high of 30 minutes, 8 seconds. The mean time to complete the loading was 14 minutes, 32 seconds, with one standard deviation of 9 minutes, 4 seconds. Extended loading times were attributed to interferences between the truck mirrors and the aircraft doorway, difficulties in separating the howitzer lunette from the truck pintle, and jacking and supporting the trails on the shoring. Although the time-consuming problems related to the jacking and shoring operation to effect separation of the truck from the gun did not bear on the basic (shoring) problem, they had a serious impact on loading time and safety. This suggested the advisability of investigation and redesign to further improve the air transportability procedure.

Some of the problems in evidence during loading did not manifest themselves at all, or at least not to the same degree, during the unloading operation. The unloading times ranged from a low of 5 minutes, 38 seconds to a high of 14 minutes, 48 seconds. The mean time to complete the unloading was 8 minutes, 44 seconds, with one standard deviation of 3 minutes, 26 seconds.

These load/unload times represented a significant improvement over the approximately 45 minutes required for the original wide tires/wheels and the shoring procedure.

In simulation of an actual airlift operation, the howitzer was flown from Pope AFB to an assault landing strip at nearby Fort Bragg. Seated next to the howitzer, which was secured by chains to the aircraft floor in accordance with AF requirements, provided an opportunity to observe the gun's behavior during flight and take note of the effects of landing on the narrow tires. There was no evidence of tire movement when the airplane hit the runway of the landing strip.

The successful outcome of the Concept Evaluation Program set the stage for the test program which determined the suitability of the narrow tires/wheels as a replacement of the wide tires and wheels.

Procedure Implemented

Implementation of the narrow wheel and tire into the M198 Howitzer Technical Data Package (TDP) was approved by ARRCOM Configuration Control Board (CCB) action in November 1983. Complementing the implementation was corresponding action to remove the wide wheel and tire from the TDP.

As a matter of clarification, the use of the word "obsolete" to describe the action taken with regard to the wide wheel and tire simply means that they have been removed from the M198 Howitzer Technical Data Parts List (TDPL). This action is not to be construed to mean that the wide wheels and tires are not suitable or acceptable for use on the howitzer.

The basic order of issue plan (BOIP) for the narrow wheels and tires provides for their optional availability to any unit authorized to have an airlift capability. Because of the strong preference for the narrow wheels and tires, as evidenced by the troop survey following the user concept evaluation tests, the option has been exercised by most units within the continental United States.

The wide wheels and tires continue to be available to those units which prefer them, however, and there is also a sizeable quantity of M198 howitzers equipped with wide wheels and tires in foreign countries. The transportability manual (ref 6), therefore, provides for a loading procedure to accommodate the howitzer in either the wide or narrow configuration.

Notwithstanding their usefulness and popularity, the narrow wheel multi-piece rims are potentially dangerous if not used properly. Strict adherence to the mounting and demounting procedures and precautions offer the most effective safeguard against injuries which could result from improper use.

IMPROVED JACKING SYSTEM AND PINTLE ASSEMBLY

Alternative Jacking Systems Considered

In dealing with the jacking problem, several concepts were developed which represented approaches designed to yield maximum benefits of improvement. Alternative no. 1 (fig. 24) was considered most desirable, offering the advantages of self-storage, quick emplacement and operational simplicity. The jack would operate in much the same fashion as those in popular usage on mobile homes and would include a telescoping column and a swiveling base to optimize compaction. Not only would the design eliminate the need for shoring, it would more significantly provide for a faster, far more effective operation. Preliminary discussion with the troops indicated that, from their operational viewpoint, this would be the optimum design in virtually every respect. Factors bearing on the decision to abandon its development were (1) an unacceptable increase in gun weight, (2) the jack's relative susceptibility to damage, and (3) the probable adverse impact on other features of the gun's design.

Alternative no. 2, also designed to facilitate the connect/disconnect operation, is illustrated in figure 25. This more elaborate design, although regarded as being sound in theory, was determined to be too complex and susceptible to damage for practical consideration. Moreover, it would have required a stack of shoring or a pedestal of some sort to support the trails in flight.

Description of Improved Jacking System

The improved jacking system and pintle assembly (figs. 26 and 27) consists of a jackstand, 5-ton worm gear actuator, 14-inch-diameter handwheel, and a yoke which serves as a connecting link and interfaces with the left spade bracket of the howitzer.

The jackstand is an aluminum weldment designed for lightweight and simplicity, with a plywood base to provide a cushioned interface between the jackstand and the aircraft floor, as required by Air Force regulations. The jackstand design was subjected to a detailed stress analysis to verify its capability to

withstand the 4.5-g forces and other loads which would be imposed upon it during loading and in flight.

The worm gear actuator (fig. 28), the heart of the system, is a commercial unit capable of supporting a static load of 5 tons (10,000 lb) on the fully extended jack screw. The precision, free-turning mechanism allows the shaft to be turned easily with one handwheel, even under the full load of approximately 4,000 lb imposed by the weight of the gun.

Due to the criticality of its function, the yoke is made of high strength steel to insure its capability to support the gun and to resist side loading. Its configuration complements the underside of the left spade bracket and takes mechanical advantage of the spade bracket features to assure proper positioning of the jackstand. The yoke also underwent extensive stress analysis to verify its strength. Its design and complexity and strength requirements suggest forging or investment casting for economical manufacture.

The complete jacking system weighs approximately 95 pounds and is designed to be handled easily by two crew members. It is estimated to cost between \$800 and \$1,000 in limited production quantities.⁵

Description of Improved Pintle Assembly

The original (and only) pintle assembly concept considered suitable for development applies a design principle used by the German military to effect operational simplicity and effectiveness (figs. 29 and 30). Although the design underwent several iterations before satisfying functional requirements, the basic concept remained unchanged.

The assembly, consisting of a front plate, back plate, and lunette pin, is secured to the front bumper of either a 2 1/2- or 5-ton truck by bolts, nuts, and washers. The front plate is a weldment of high strength, 3/8-inch-thick steel with elongated holes in the top and bottom plates to accommodate forward and aft movement of the lunette pin, and a locking feature on the underside of the bottom plate to secure the lunette pin when the assembly is not being used in airlift operation. Made of high strength steel with a stop collar and lifting handle, the lunette pin is case-hardened to resist nicks and other damage which could interfere with easy insertion and removal. All elements of the pintle assembly were stress analyzed in consideration of an approximately 4,000-lb downward load imposed by the gun and a rolling force of approximately 16,000 lb acting on the lunette pin. The pintle assembly weighs approximately 60 lb and is easily mounted on the front bumper with a standard wrench. It is estimated it will cost between \$300 and \$400 in limited production quantities.

⁵ All cost estimates were calculated in 1984.

Improved Jacking System and Pintle Assembly Tested

A prototype version of the improved jacking system design selected to reduce jacking time and eliminate shoring requirements was tested for fit and function in a simulated loading operation at APG in December 1983. The jacking procedure was tested concurrently with a prototype version of the first generation design of the new pintle assembly bolted to the front bumper of the 2 1/2-ton truck. The test was performed at a truck loading ramp which approximated the ramp angle of the C130 cargo plane, with participation by representatives of the user (Fort Sill) and the APG Human Engineering Laboratory.

In the first phase of the test the gun was easily pushed up the ramp to the approximate position in which it would be located in the airplane. The jack was placed under the left spade bracket of the gun and the handwheels cranked by two gun crew members until the gun's lunette cleared the bottom plate of the pintle assembly; elapsed jacking time, approximately 1 minute and 5 seconds. The lunette pin was removed, the truck backed out of position, and the handwheels were then turned until the yoke was resting solidly on the jack; elapsed time, approximately 35 seconds.

The simulation test demonstrated the soundness of the design concept for the improved jacking procedure and pintle assembly and their acceptability as a replacement of the existing method of jacking and shoring to separate the gun from the truck and support the gun in flight.

The simulation test suggested, however, the advisability/acceptability of several minor changes to effect weight reduction and design optimization. Plans called for a new prototype of the pintle assembly reflecting the design changes for use in a user evaluation test scheduled to be conducted under the direction of the U.S. Army Airborne Board to validate the acceptability of the improved jacking system and pintle assembly.

The user evaluation tests conducted at Fort Bragg and Pope AFB during March 1984 dramatized several deficiencies in the pintle assembly design which were not manifested during the simulation tests conducted at APG in December 1983. A pronounced, potentially dangerous bow in the fully extended jack screw during disconnect was attributed to off-center loading on the yoke and insufficient clearance between the yoke and gun to permit the yoke to slide on the spade bracket. The heavy dent in the tubular construction lunette pin, which prevented removal of the pin from the pintle assembly, was attributed to a quick stop while maneuvering the gun for loading, causing the lunette to crush the wall of the tubing. The yoke was modified to overcome its defects and a prototype (solid) lunette pin was manufactured for use in another prove-out test. The user tests also yielded a decision to increase the base of the jackstand from 12 x 34 1/2 in. to 18 x 36 in. to insure against possible tipping. This change was reflected in the final configuration.

A simulation test conducted at Pope AFB in May 1984, using a C130 mock-up revealed that the design changes to the pintle assembly and jack screw yoke did not yield the anticipated results. The problem with the bow in the jack screw was determined to be inherent in the geometry of the elements involved as the

jacking operation takes place. It was decided that a modification to the loading procedure to allow the gun to move with the truck during jacking would compensate for the geometry problem and prevent a bow in the jack screw. Changes were made to the pintle assembly to provide for self-alignment of the lunette in the pintle and facilitate removal of the lunette pin.

A loading test conducted with a C130 cargo plane at Pope AFB in July 1984 showed that neither of the above changes effected a meaningful resolution to the screw-bowing problem. A significant change in the pintle design was determined necessary to compensate for the geometry problems which continued to plague the operation. (The geometry problems were not peculiar to the new pintle assembly; they also plagued the original procedure, in which the standard coupling was used.)

A final configuration of the pintle assembly, reflecting the design changes necessary to overcome all the deficiencies manifested during previous testing, was satisfactorily tested at a simulated loading operation at Fort Bragg in September 1984. This fifth in a series of tests to optimize the design of the improved jacking and pintle assembly was witnessed by and met with the approval of representatives of all cognizant agencies. The test showed that revising the pintle design to change the round lunette pin hole to a slot and rotating the top and bottom plates to an angle corresponding to the aircraft ramp angle provided the relief necessary to allow a virtually effortless removal of the lunette pin from the pintle assembly.

Actual aircraft loading tests conducted at Fort Bragg during October 1984 were highly successful. The improved air transportability procedure, consisting of narrow tires, new jacking system, and pintle assembly required an average loading time of 6 to 8 minutes, as opposed to the approximately 45 minutes required by the original procedure.

The improved on and off-loading procedures are illustrated in figures 31 and 32.

Independent Design and Producibility Assessment Reviews

The independent review of the improved jacking system and pintle assembly designs evoked nine areas of concern, five of which were identified as "specific," i.e., those directly design related, and four "general" concerns relating to Army and/or Air Force system, equipment, and/or procedural weaknesses. In actuality, seven of the nine were systems and/or logistics oriented and did not bear in any way on the design of either element. A general concern suggesting the need for formal documentation testifying to Army/Air Force agreement to assure the availability of all material and personnel necessary to support the on/off loading operations was regarded as clearly beyond the scope of study objectives. A worst case environmental test advocated as part of a general concern alluding to potential loading problems under unimproved field conditions was also outside the scope of study objectives.

The review panel's treatment of matters of specific, design-related concerns prompted modifications to the pintle assembly which materially enhanced its functional characteristics.

The findings of the independent review (IR) panel indicated that all of the performance requirements specified by the engineering study's scope of work were satisfactorily met. However, the IR team's recommendation for approval of the improved jacking system and pintle assembly as an M198/C130 air transportability kit was contingent upon a satisfactory stress analysis and an evaluation of general system parameters by a higher command. These conditions were subsequently met to the satisfaction of the IR panel.

The producibility assessment review concluded that the design features and construction of the jacking system and pintle assembly posed no producibility problems and that they could be easily and economically produced using standard materials and manufacturing processes.

Based upon the recommendations of the independent and the producibility assessment review panels, as well as those of the reviewing officer, the improved jacking system and pintle assembly were approved for incorporation into the M198 howitzer TDP.

Kits Implemented

The January 1985 implementation of the improved jacking systems and pintle assembly kits, complementing the implementation of the narrow wheels and tires in November 1983, completed all actions related to the engineering study to improve the air transportability of the M198 howitzer in a C130 cargo plane.

The BOIP for the jack stand and the worm gear actuator comprising the jacking system provides for one kit for each M198 howitzer to be carried in the bed of the 5-ton truck (primer mover). The plan of issue of the improved pintle assembly provides for two kits to be made available to each battery of eight howitzers to accommodate the two 2 1/2-ton trucks expected to support each battery. Although the complete pintle assembly would also easily fit in the bed of the prime mover, it is more likely that, once attached, the pintle assembly will remain on the front bumper of the 2 1/2-ton truck.

CONCLUSIONS

The study dramatized the capability of a program targeted to resolve specific problems to yield substantial fringe benefits. The tests performed to validate the improved air transportability procedure for the M198 howitzer also demonstrated the acceptability of narrow tires as a replacement for the howitzer's original wide tires. The net effect of the study, therefore, was not only a vastly improved, easier, safer, cheaper, logistically simpler, and much faster

loading procedure, but a more economical, equally effective improvement in the howitzer's tire and wheel configuration.

This study also shows that opportunities for system optimization can be forfeited due to a failure to analyze all of the elements of an operation for their effectiveness. Deficiencies associated with the jacking and shoring effort to effect gun/truck separation, an integral part of the loading procedure, were forcefully manifested when the narrow tires were demonstrated to have solved the basic problem. The development and implementation of an improved pintle assembly and jacking system, undertaken as part of the expanded study, further optimized the loading operation and enhanced the ease, safety, and speed with which it is accomplished.

RECOMMENDATIONS

Further optimization of the air transportability procedure requires reappraisal of concepts deemed unacceptable at the time of original consideration. There are two potential areas worth reevaluating: the bogey wheel concept and the rough terrain military forklift.

Bogey Wheel

The 2 1/2-ton truck, with its steering problems, limited power, and other deficiencies, severely inhibits the ease, speed, and safety with which the loading and unloading operation is accomplished. A practical alternative as a loading vehicle is the 5-ton truck with a bogey wheel to support the weight of the gun's trails in the stowed configuration.

The bogey wheel concept was developed into an Air Force-approved design which offers broad application at comparatively low cost and logistics impact. Its modular design and construction facilitates positioning the gun within the airplane and motor park, assembly to and removal from the gun's trails, and handling and storage in the bed of the prime mover. The wide angle of vertical movement of the connecting tongue compensates for the disparity in height between the lunette and pintle to allow for easy connecting and disconnecting.

In the loading operation, with the bogey wheel attached to and supporting the trails and connected to the pintle on the front bumper of the 5-ton truck, the gun would be pushed into position in the airplane and secured for flight. During unloading, consideration could be given to backing the truck into the airplane, connecting the bogey wheel to the rear pintle, and towing away in probably less than half the time required by the current improved procedure using the 2 1/2-ton truck and jacking system. The gun could then be towed to a tree-line or other point at which it could be converted to the towing configuration and the bogey wheel removed.

It is recommended that the basis for rejection of the bogey wheel concept, i.e., lack of storage space, limited utility, etc., be reevaluated and a study performed to determine its acceptance and usefulness as part of the loading procedure. The bogey wheel would eliminate the need for the jacking system, with its attendant time and logistics implications, and eliminate all shoring requirements.

Rough Terrain Military Forklift

It is recommended that cognizant elements of the artillery community reassess the merits of the MC4000 forklift for use in artillery regiments. The benefits of the MC4000 include its basic utility for ammunition handling and other material handling operations, forklifting the trails when the gun is in either the stowed or towing configuration, and moving and tight positioning the gun in a motor park or other area. An electric winch attached to the rear hood can be used for vehicle removal and other purposes.

Table 1. Alternative loading procedures

Alternative	Estimated Impact		Feasibility value*	Anticipated benefits	Anticipated drawbacks	Remarks
	Cost	Time				
No. 1. Continue existing procedure.	None (see remarks)	None	N/A	Avoids engineering effort, manual changes and costs to develop new procedure.	Time-consuming, costly procedure. Risk of shoring being lost/stolen.	Intenable situation. Procedure unacceptable to FORSCOM.
No. 2. Reduce width of tires/wheels	Over \$50K	Over 12 mos	0	Elimination of shoring, significant reduction in on/off loading time, reduced troop exposure, other benefits.	Reduced gun stability during towing. Less flotation in soft terrain.	Retrofit required - concept considered fundamentally prohibitive.
No. 3. Change from standard to dual wheels.	Over \$700K	Over 15 mos	0	Elimination of shoring, reduced loading time, reduced troop exposure, other benefits. Increased gun stability and flotation during towing.	Massive redesign effort impacting gun. Extensive manual changes.	Retrofit required - concept considered fundamentally prohibitive.
No. 4. Remove lugs/risers from C13 when air lifting gun.	None	None	0	Elimination of shoring, reduced loading time, reduced troop exposure, and other benefits.	Rails/bolts required for A/C structural integrity. Approx. 8 hrs required for removal/replacement.	AF adamantly opposed to removing rails. Idea considered fundamentally prohibitive.
No. 5. Replace timber shoring with molded or extruded sections.	\$30K	9 mos	3	Reduced handling and load/unload time. Increased shoring stability.	Risk of shoring being lost/stolen.	Replace 75 pieces with 25 pieces.
No. 6. Supplementary (donut) tire over existing tire.	\$100K	12 mos	3	Elimination of shoring. Reduced on/off loading time.	Difficult steering. Storage problems. Risk of donut being lost or stolen. Would require extensive design effort (study). Long mounting time.	Tire supplier reluctant to develop donut. Concept considered essentially prohibitive.

Table 1. (cont)

Alternative	Estimated Impact		Feasibility value*	Anticipated benefits	Anticipated drawbacks	Remarks
	Cost	Time				
No. 7. Skis mounted on bottom carriage.	\$150K	12 mos	2	Elimination of shoring. Reduced on/off loading time.	Ski/roller alignment problems. Does not address traversing A/C ramp. Extensive effort to design skis, attach to carriage. Storage problems. Risk of skis being lost or stolen.	Concept presents myriad of problems; considered essentially prohibitive.
No. 8. Use A/C pallet to support gun in A/C.	None	None	8	Alleviates gun steering problems. Reduced shoring requirements. Would permit 5-ton truck for loading.	Would require loading in towing configuration; requiring AF waiver.	Probably simplest, fastest, most economical alternative.
No. 9. Dolly under carriage to support roll gun.	\$150K	12 mos	5	Elimination of shoring. Anticipated reduced loading time.	Storage problems when not in use. Major modification to bottom carriage. Major effort to design dolly.	Dolly would allow gun wheels to be raised above rails. Implies all terrain tires.
No. 10. Gun on "bogie" wheel, jack, and pallet.	\$150K	12 mos	3	Elimination of shoring. Some reduction in on/off loading time. Overcomes 5-ton truck axle weight problem.	Some shoring required. Extensive design and test efforts required. Risk of "bogie" wheel being lost or stolen.	Lack added to trails concept considered essentially prohibitive.
No. 11. Trails supported by "ammo" trailer	\$50K	6 mos	4	Some reduction in on/off loading time.	Steering problems. Modification to trailer required. Questionable availability of empty trailer.	Trailer serves as dolly similar to "bogie" wheel. Method to connect trails to trailer required.
No. 12. Retractable wheels.	\$200K	15 mos	2	Rapid emplacement of retractable wheels. Some reduction in on/off loading time.	Steering problems. Significant increase in gun weight. Wheels only good for A/C load/unload. Interference with other parts of gun.	Extensive/very costly design changes. Concept considered essentially prohibitive.

* Based on a scale of 1 to 10, with 10 being the most feasible.



Figure 1. Relationship of wide tire and shoring to LAPES rails

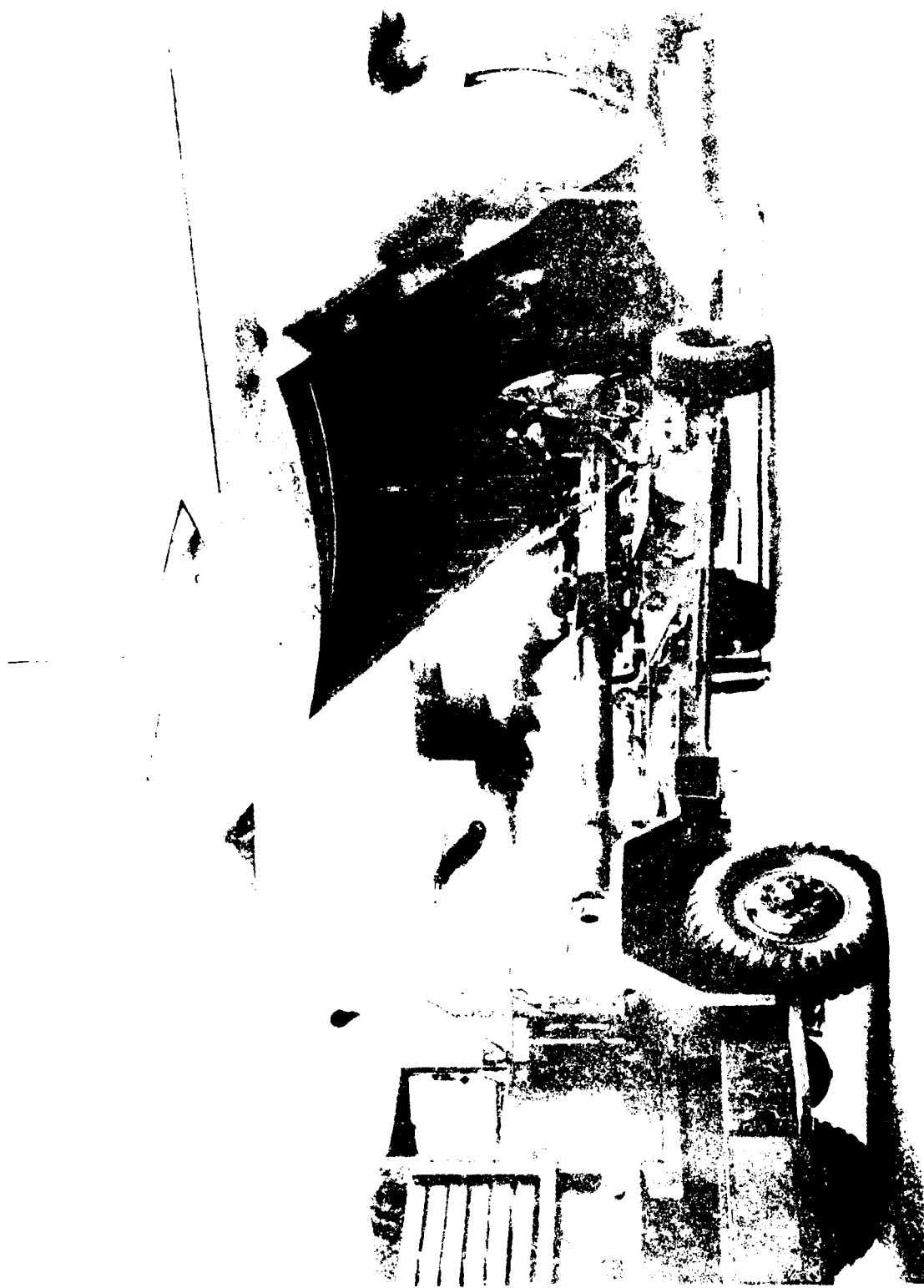


Figure 2. M198 howitzer with wide tires being loaded by original procedure



Figure 3. Part of the truckload of shoring required for the original loading procedure



Figure 4. Shoring on aircraft ramp required for original loading procedure

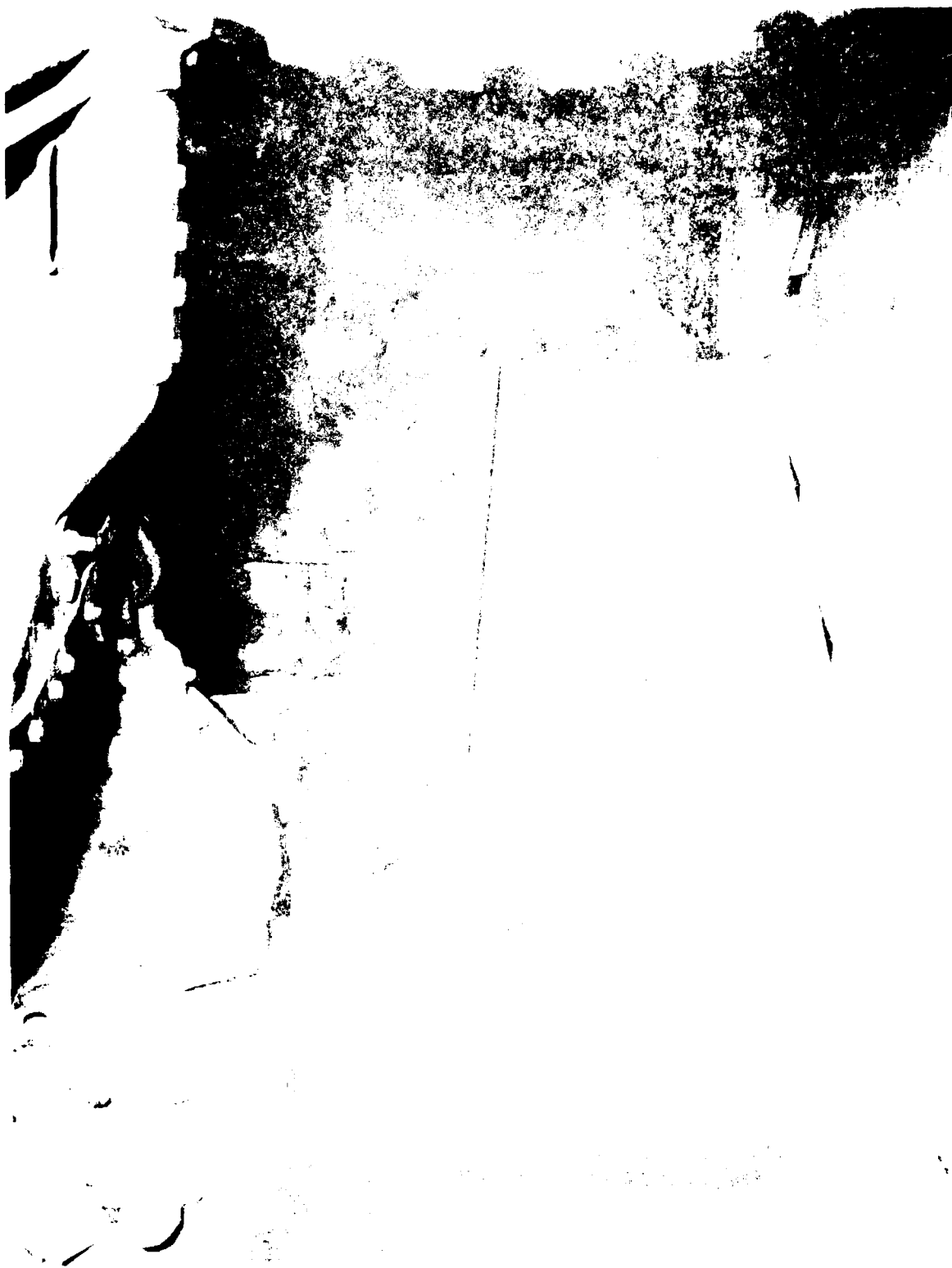


Figure 5. Lack and shoring required for original loading procedure



Figure 6. Gun secured for flight using original loading procedure

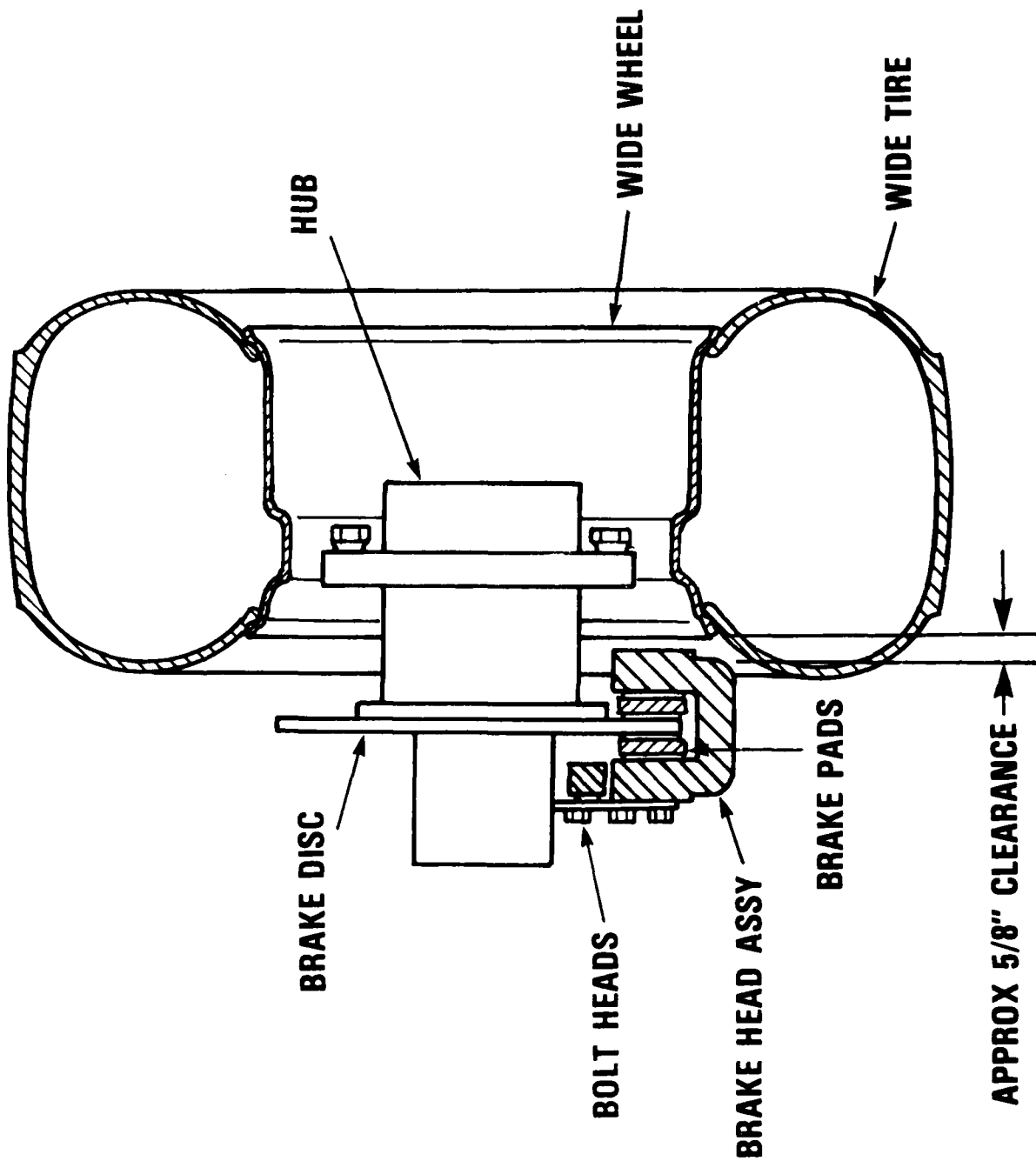


Figure 8. Relationship of M198 howitzer wide wheel to brakehead assembly

NOTES:

1. CHARACTERISTICS:
 - A. MATERIAL: SHALL MEET REQUIREMENTS OF ZZ-T-381.
 - B. SIZE: 16.5 X 19.5
 - C. TREAD DESIGN: CUSTOM MIMILER TRANSPORT B-304
 - D. PLY RATING: 16 PLY NYLON
 - E. TUBELESS TYPE BLACKWALL, SUPER SINGLE DUPLEX
 - F. DESIGNED TO BE MOUNTED ON ONE-PIECE RIM, SIZE 12.25 X 19.5
 - G. OPERATING TEMPERATURE RANGE: -65°F TO +140°F
 - H. OZONE RESISTANCE: SHALL MEET REQUIREMENTS OF MIL-T-12459
 - J. FUNCTIONAL REQUIREMENTS:
 1. CONTACT AREA AT 75 PSI AND 7480 LB. LOAD: 119 SQ. IN. APPROX.
 2. STATIC LOADED RADIUS AT 75 PSI AND 7480 LB. LOAD: 19.2 IN. APPROX.
 3. STATIC LOAD AT 95 PSI INFLATION: 16,140 LB. MAX
 4. LOAD AT 5MPH AT 85 PSI INFLATION: 12,780 LB. MAX
 5. LOAD AT 10MPH AT 65 PSI INFLATION: 9340 LB. MAX
 6. LOADS AT 30MPH:
 - A. AT 45 PSI INFLATION: 6720 LB. MAX
 - B. AT 55 PSI INFLATION: 7560 LB. MAX
 - C. AT 65 PSI INFLATION: 8340 LB. MAX
 7. LOADS AT HIGHWAY SPEEDS:
 - A. AT 45 PSI INFLATION: 5360 LB. MAX
 - B. AT 55 PSI INFLATION: 6030 LB. MAX
 - C. AT 65 PSI INFLATION: 6780 LB. MAX
2. APPLY PART NO. PER MIL-STD-130.
3. IDENTIFICATION OF THE SUGGESTED SOURCE OF SUPPLY HEREON IS NOT TO BE CONSTRUED AS A GUARANTEE OF PRESENT OR CONTINUED AVAILABILITY AS A SOURCE OF SUPPLY FOR THE ITEM.

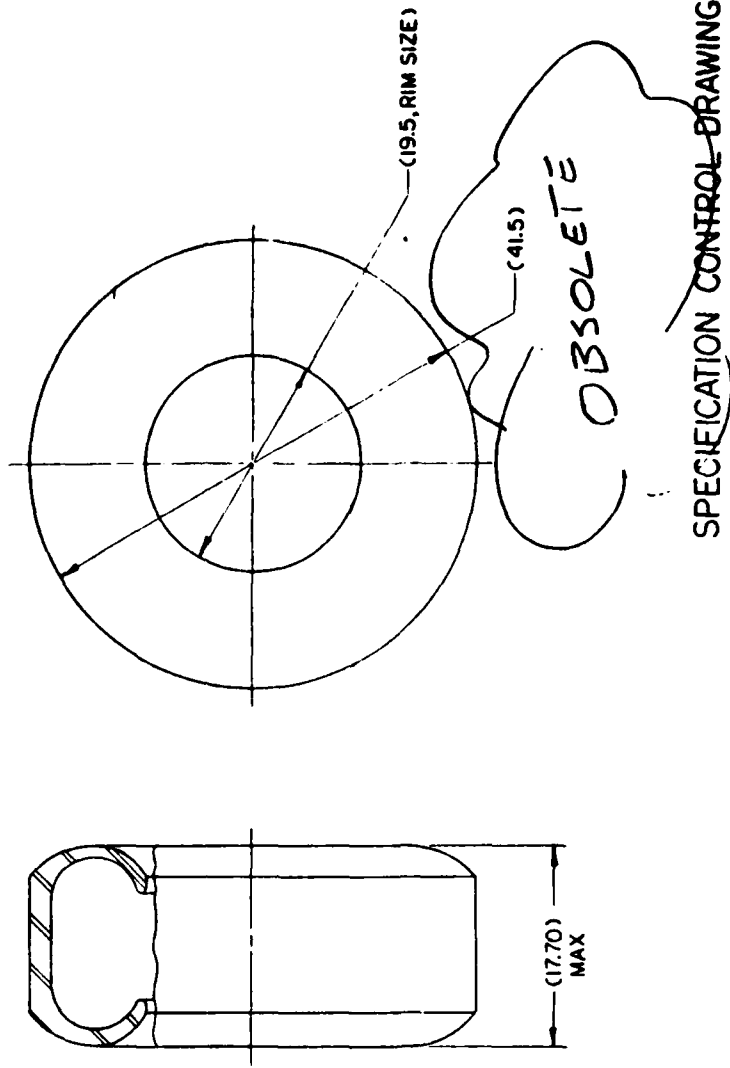
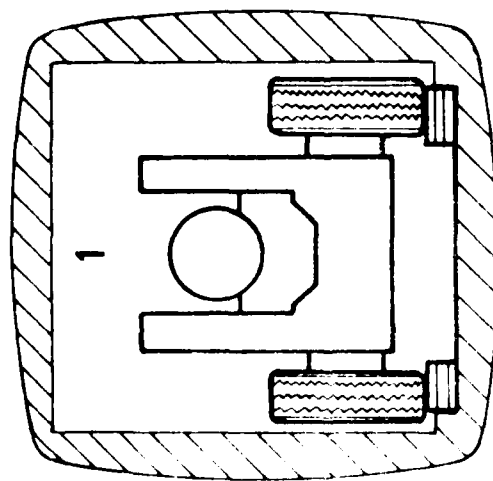
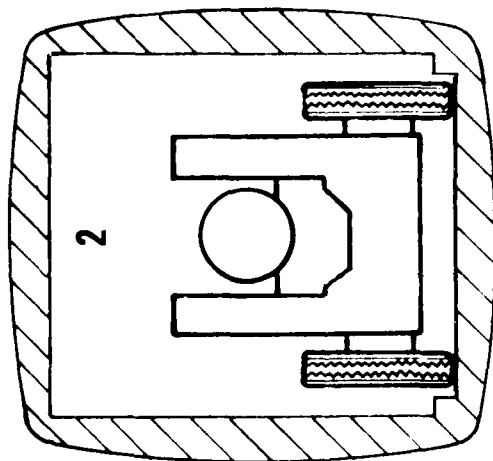


Figure 9. Wide tire used in original gun design

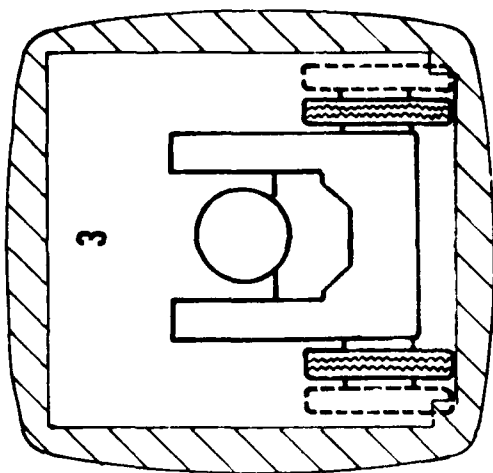
VIEW FROM BREECH END



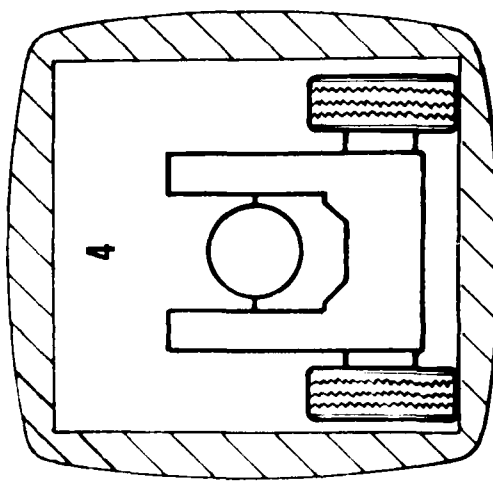
WIDE TIRES/SHORING



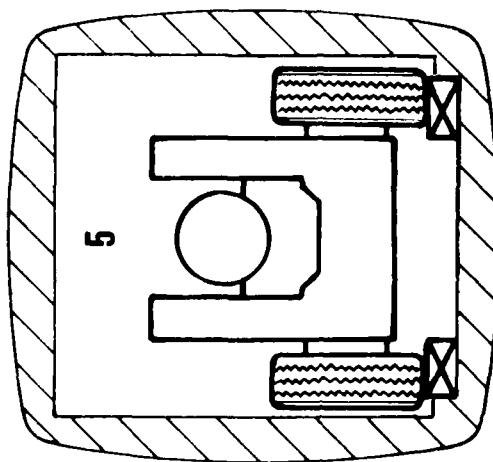
NARROW TIRES



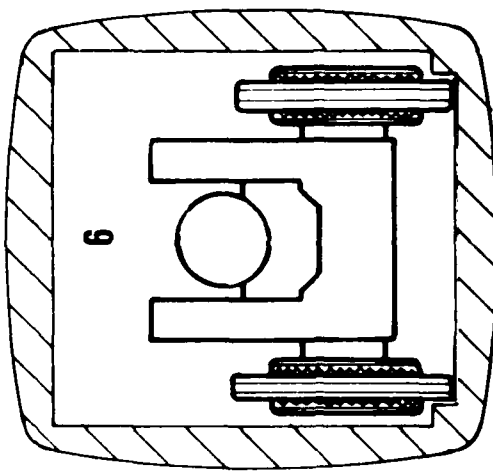
DUAL WHEELS



RAILS REMOVED



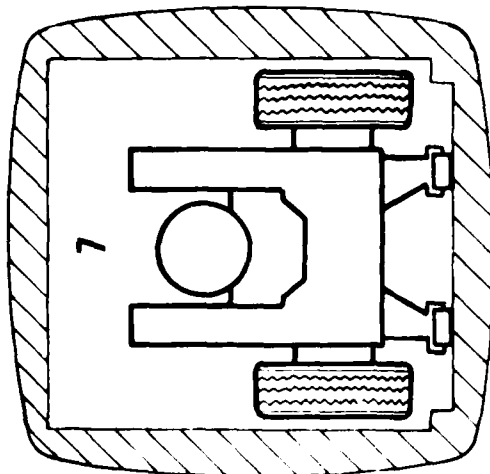
WIDE TIRES/EXTRUSIONS



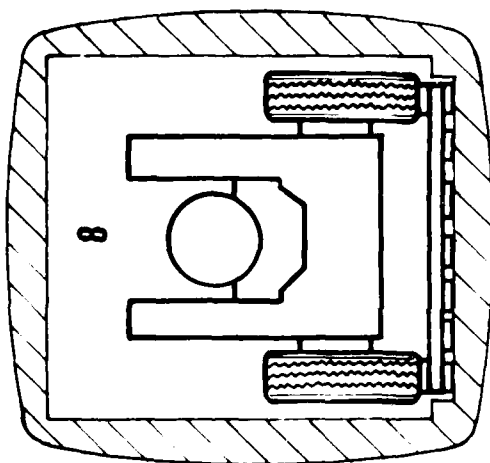
WIDE TIRE/DONUT

Figure 10. Alternative loading procedures investigated

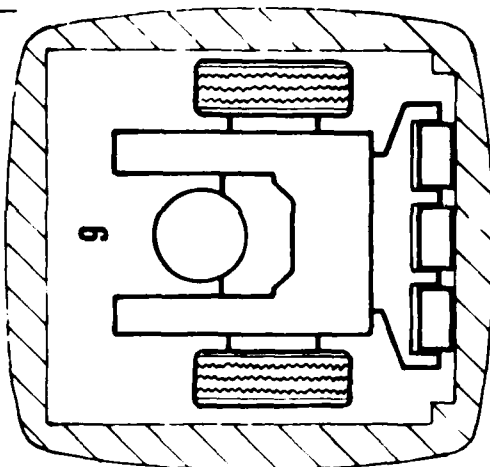
(VIEW FROM BREECH END)



SKIS ON A/C ROLLERS

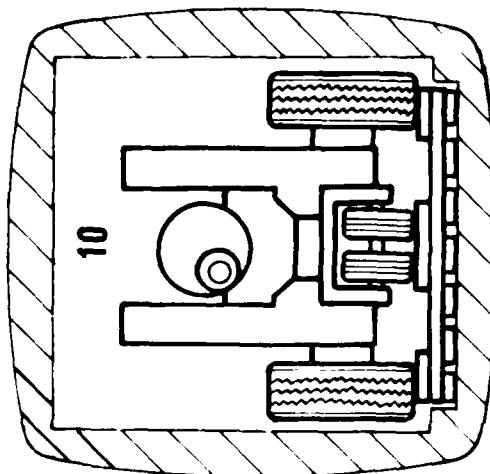


PALLET ON ROLLERS

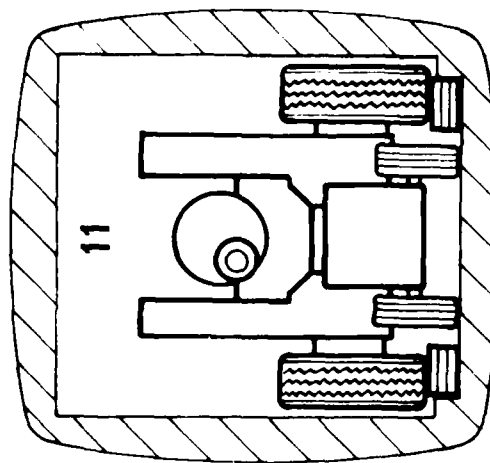


RUBBER TIRE DOLLY

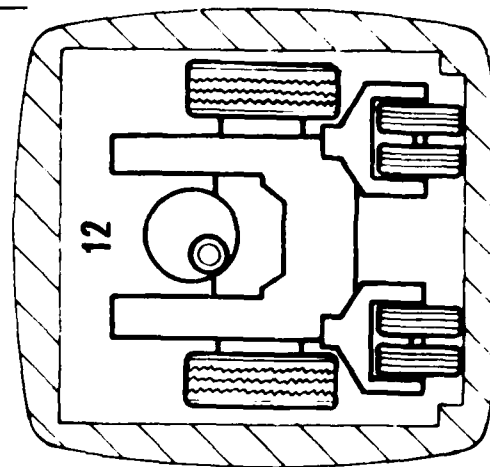
(VIEW FROM MUZZLE END)



BOGEY WHEEL/PALLET



TRAILER AS BOGEY



RETRACTABLE WHEELS

Figure 10. (cont)

DUAL WHEEL CONCEPT

- OUTER WHEELS ON FOR
NORMAL TOWING
- OUTER WHEELS OFF FOR
AIR TRANSPORTABILITY

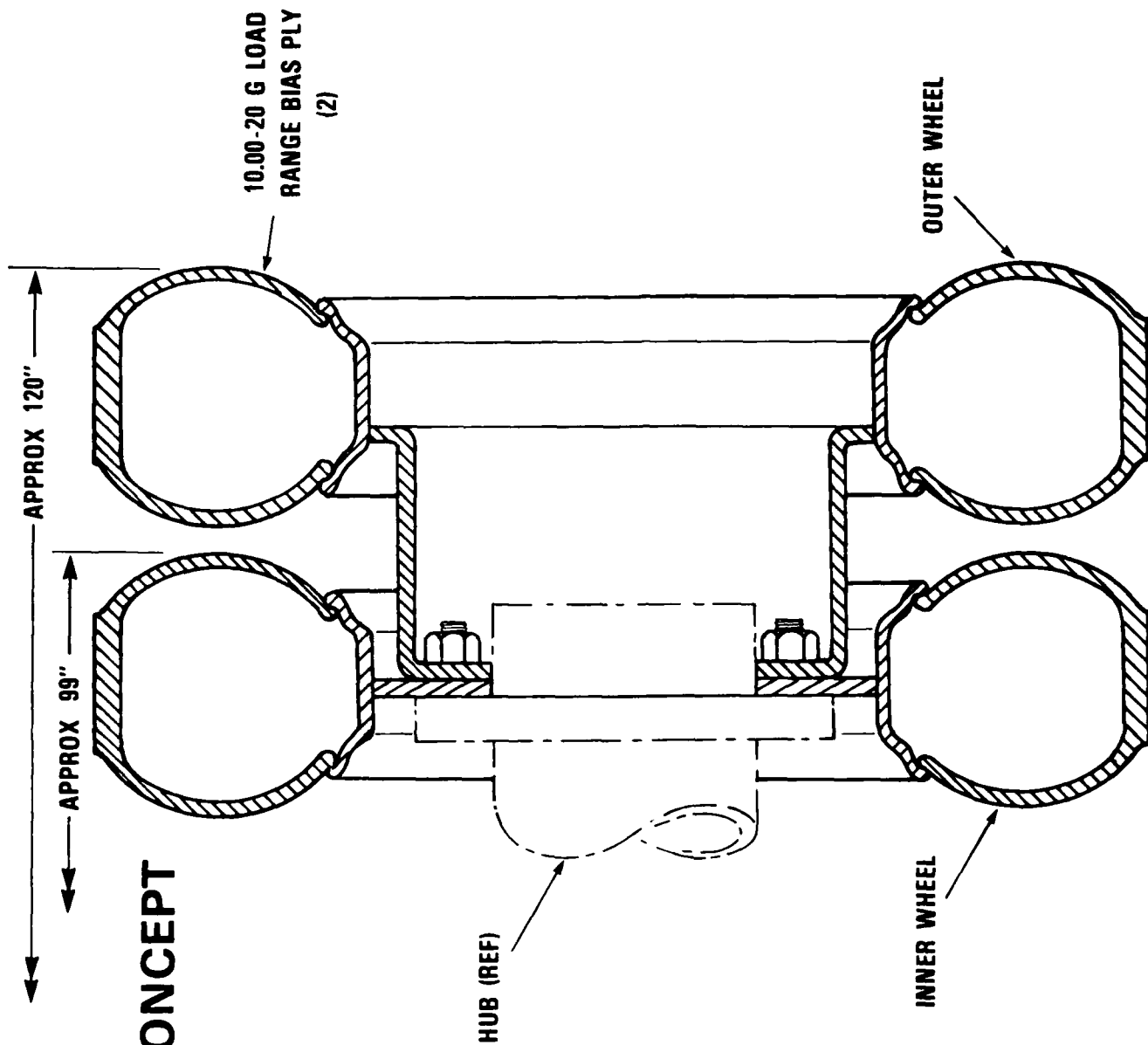


Figure 11. Dual wheel concept

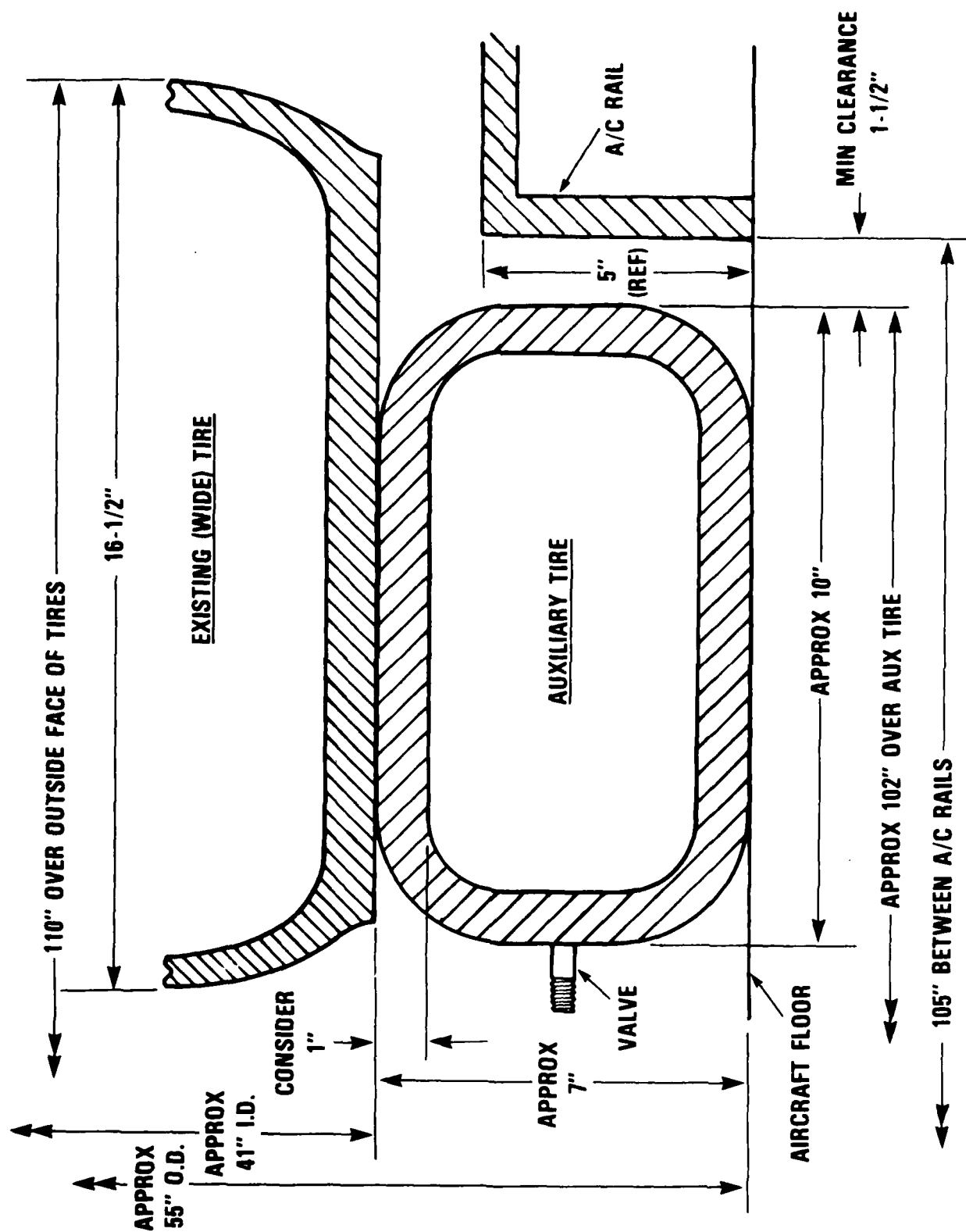


Figure 12. Auxiliary tire for M198 air transportability

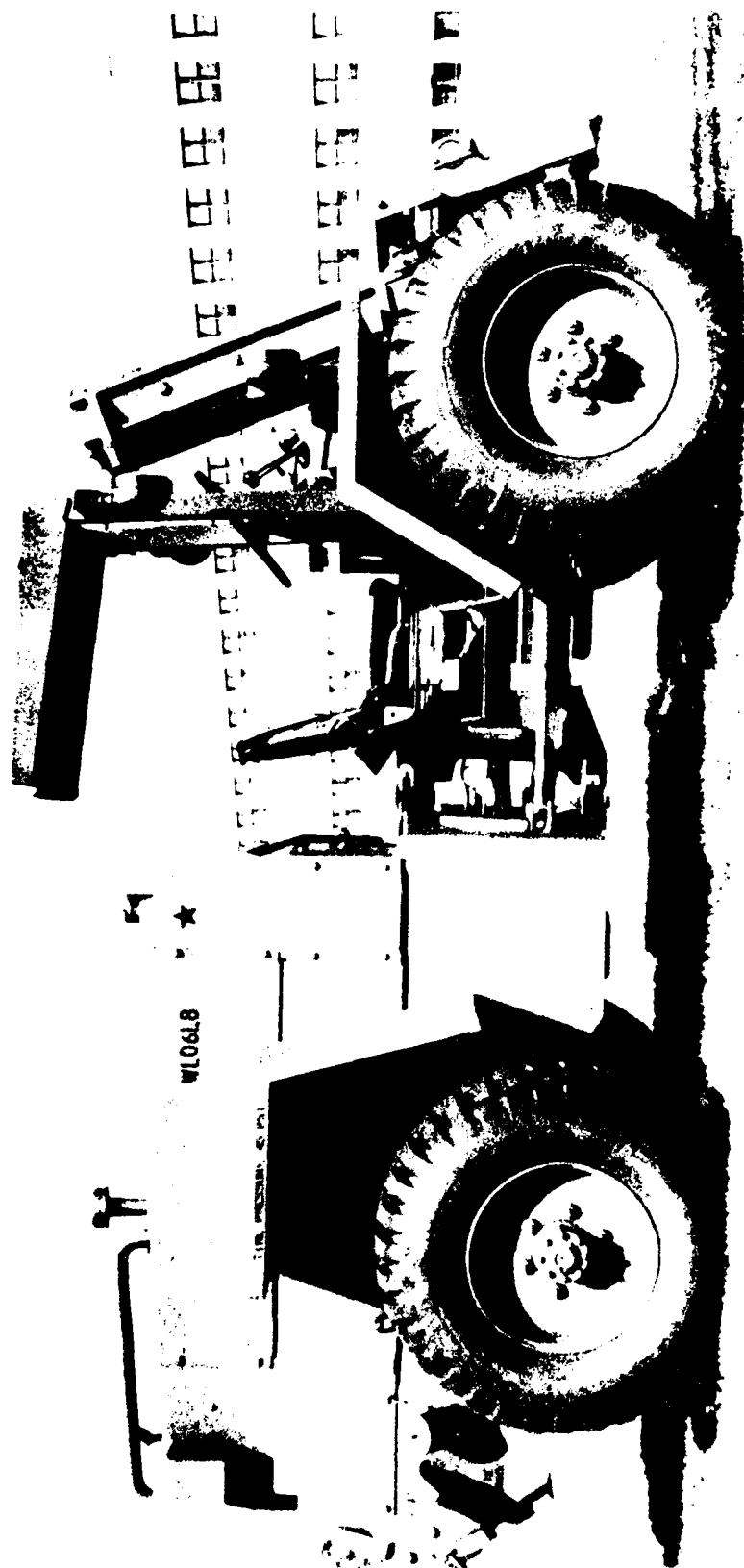


Figure 13. Case MC4000 rough terrain military forklift

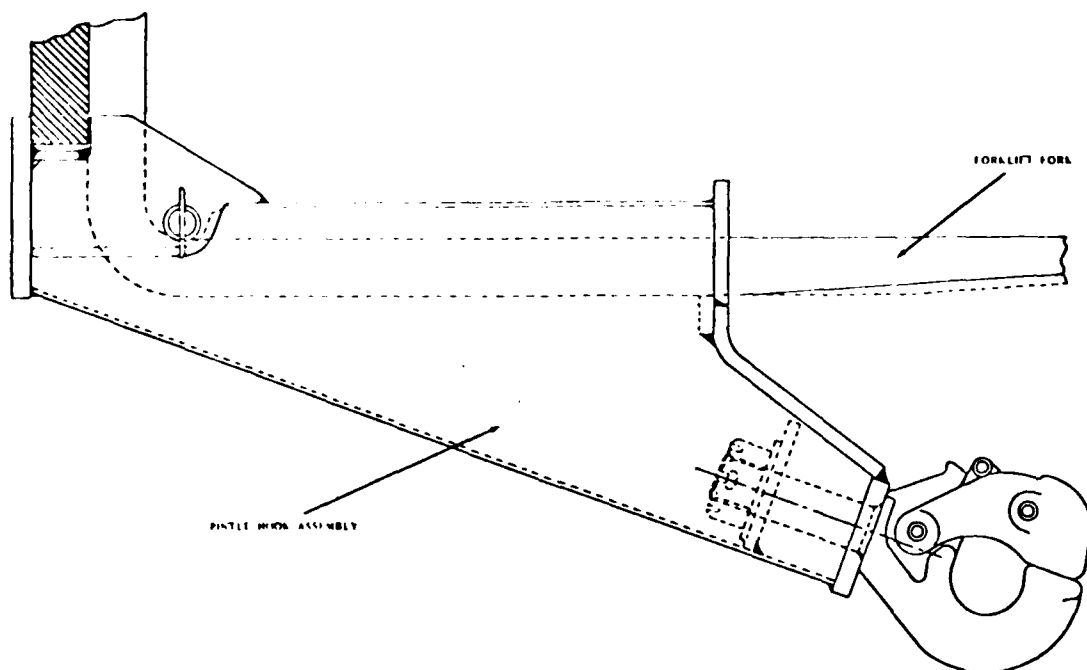
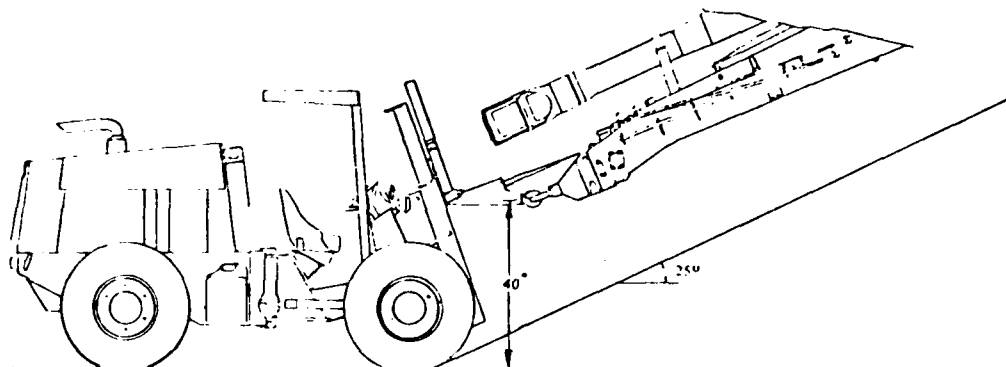
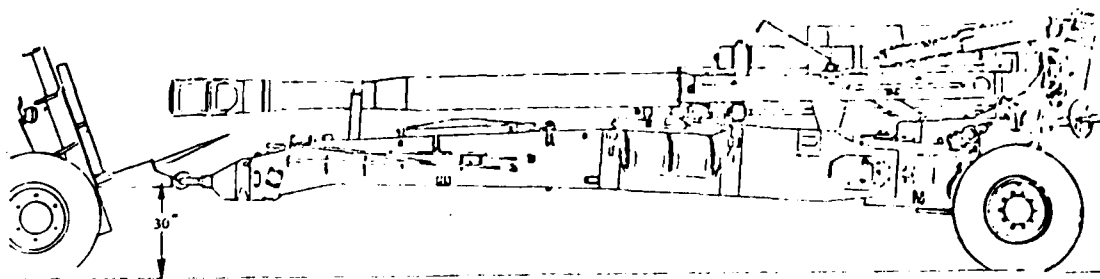


Figure 14. Case MC4000 forklift with pintle hook assembly

**BOGEY WHEEL TO PERMIT USE OF
5 TON TRUCK FOR LOADING M198
HOWITZER ON C-130 CARGO PLANE**

- APPROX WT: 300 LBS
- APPROX CUBAGE: 32 CU FT

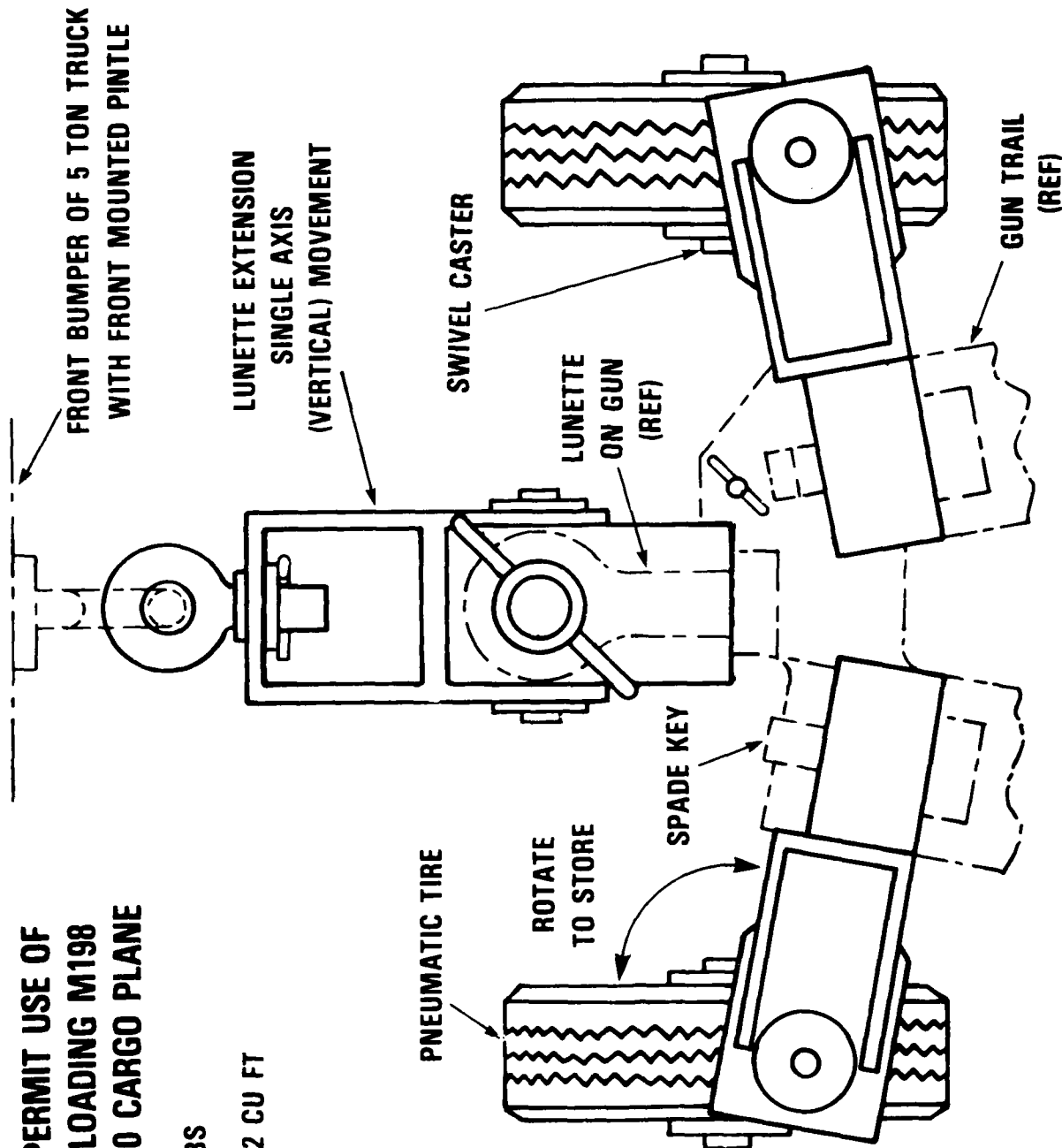


Figure 15. Bogey wheel concept

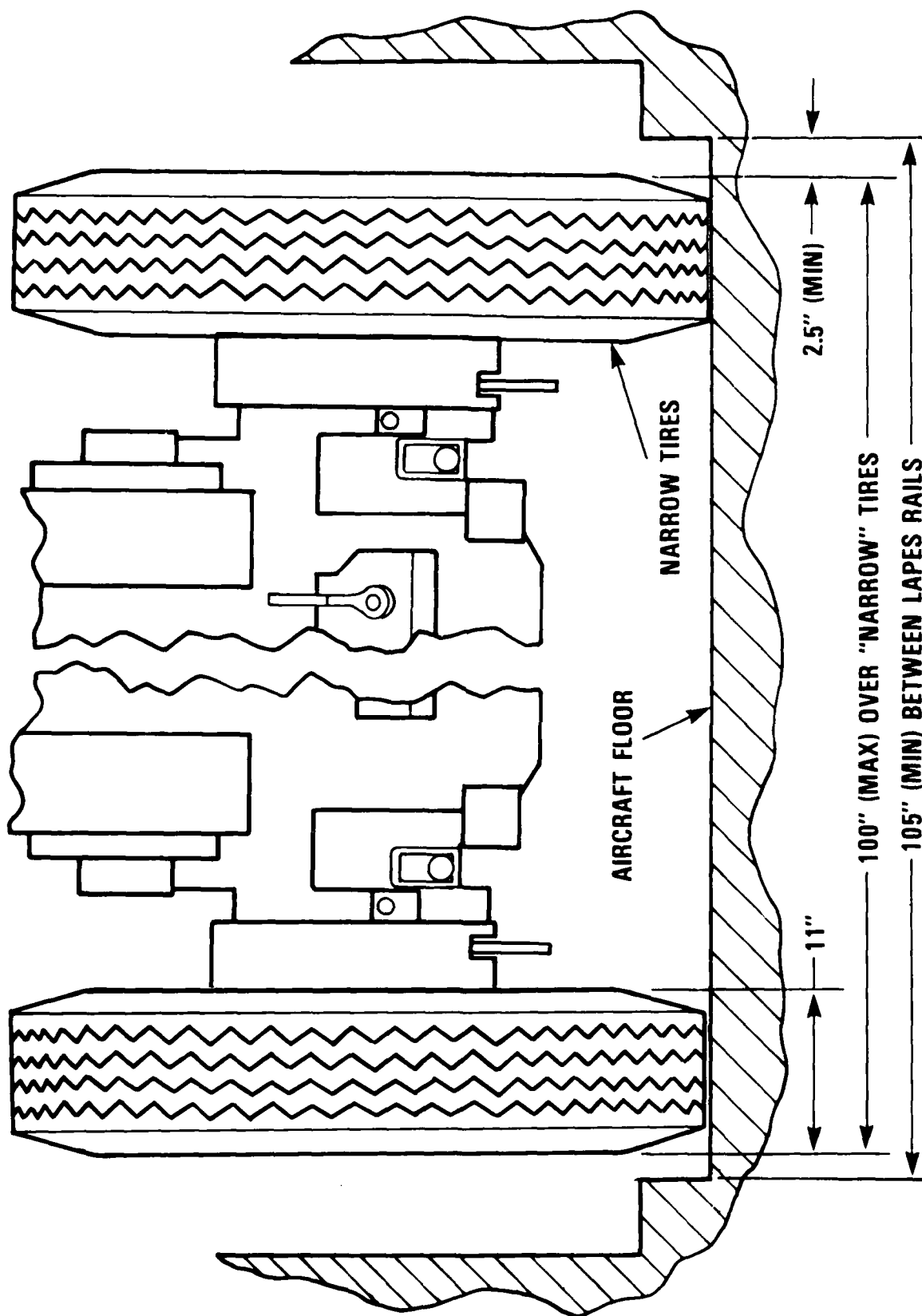


Figure 16. Improved loading procedure

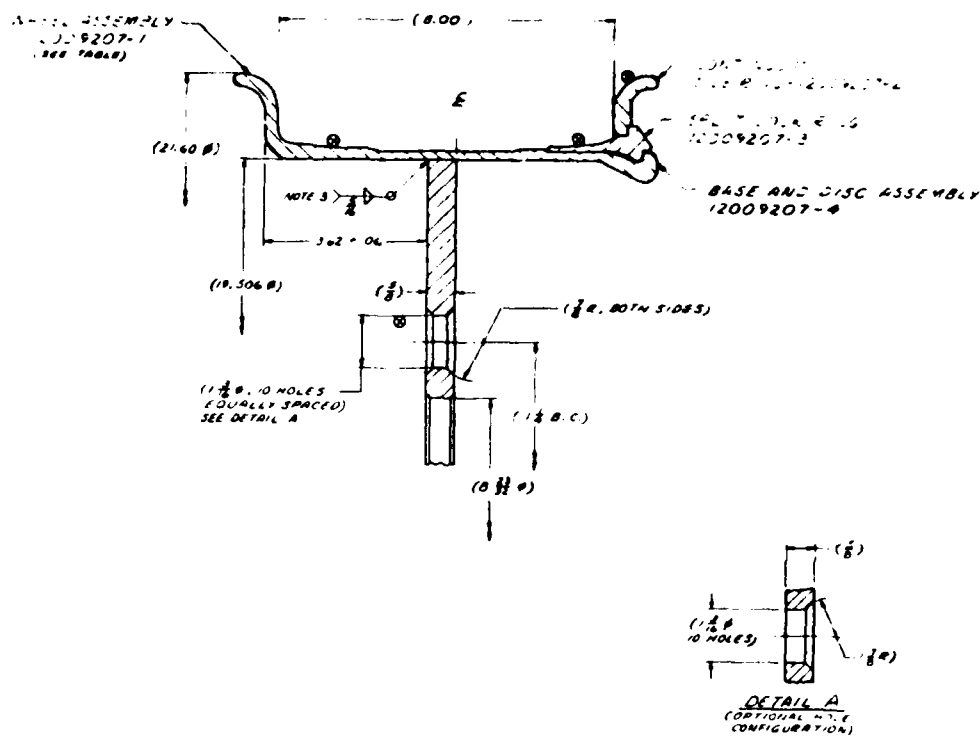


Figure 17. Narrow wheel assembly for improved loading procedure

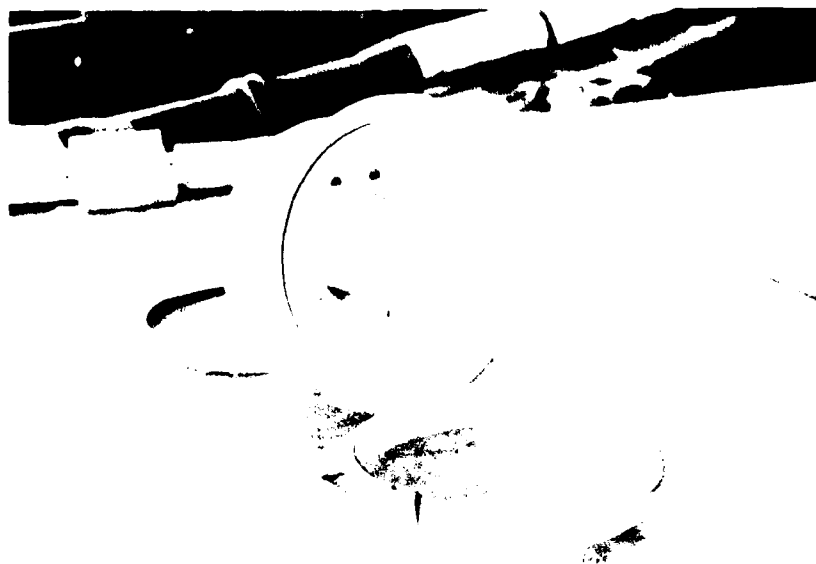


Figure 18. Narrow tire split rim

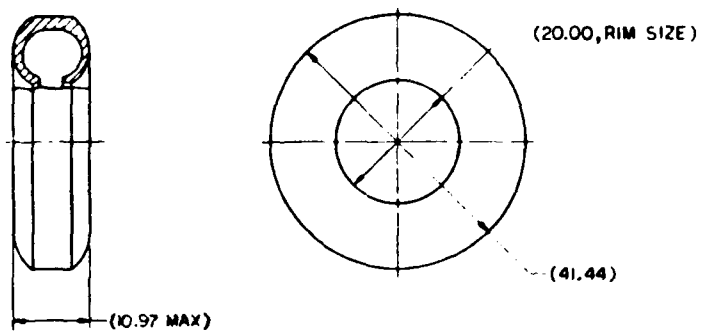


Figure 19. Narrow tire for improved loading procedure

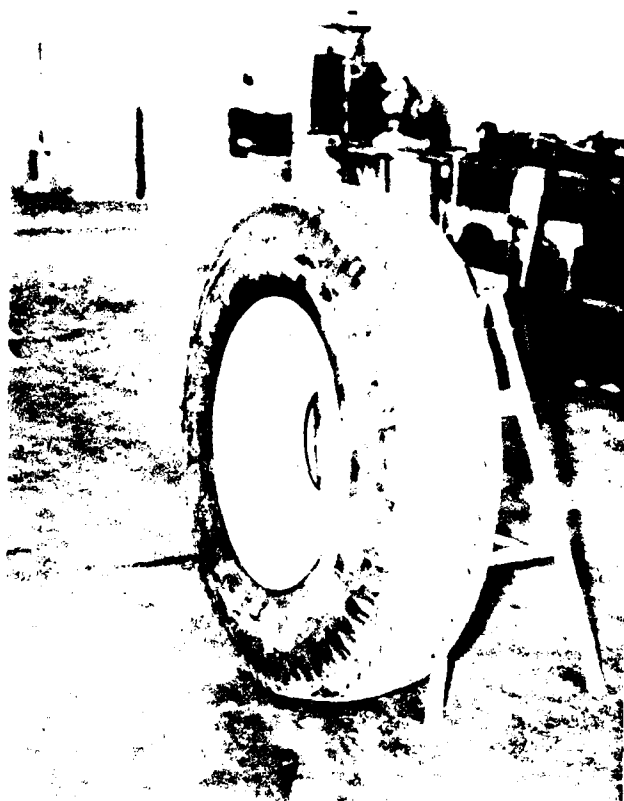


Figure 20. Sideview of narrow tire with split rim



Figure 21. Comparison of standard (wide) and narrow tires

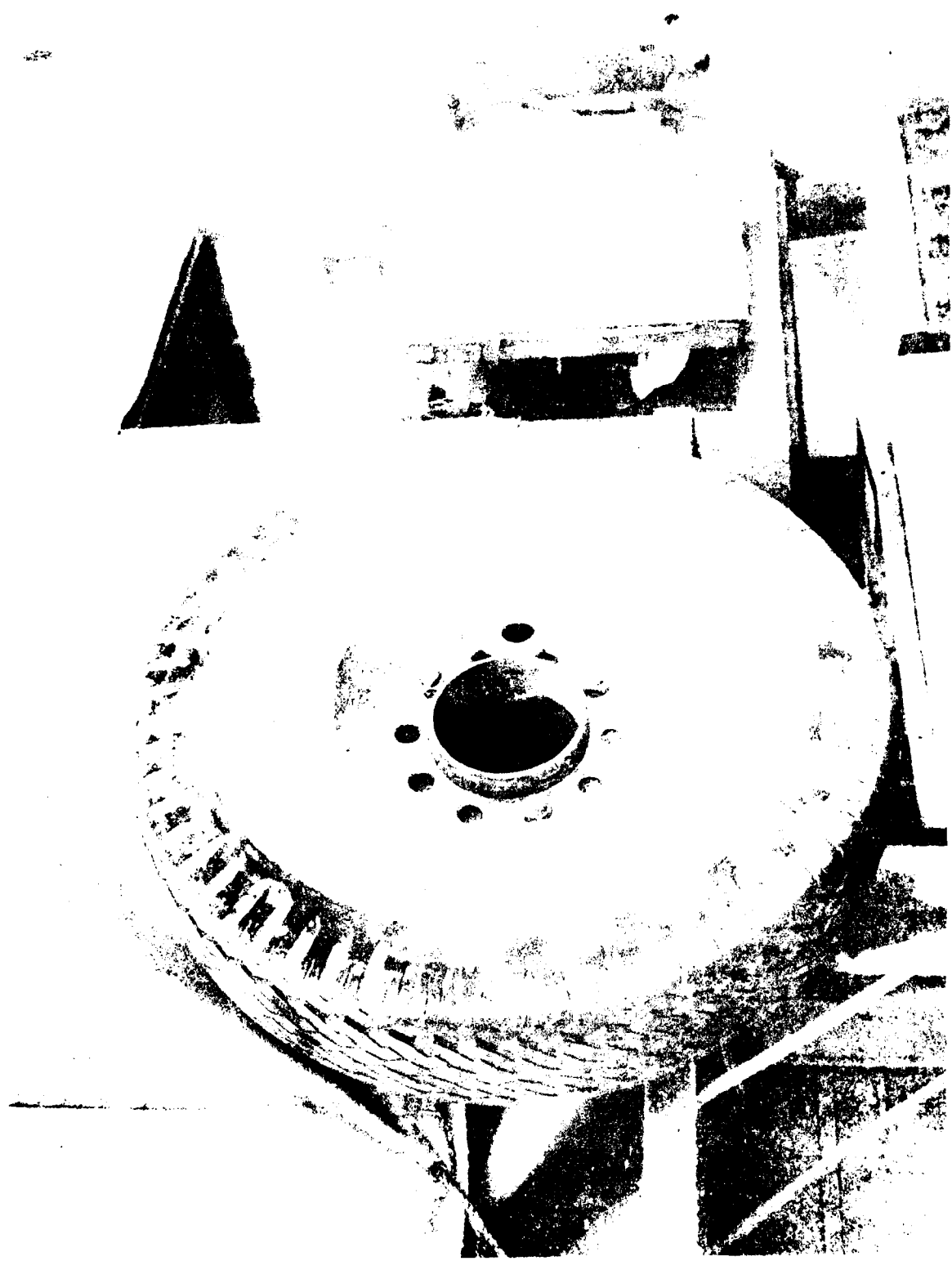


Figure 22. Narrow wheel mounted on wheel bracket on side of prime mover

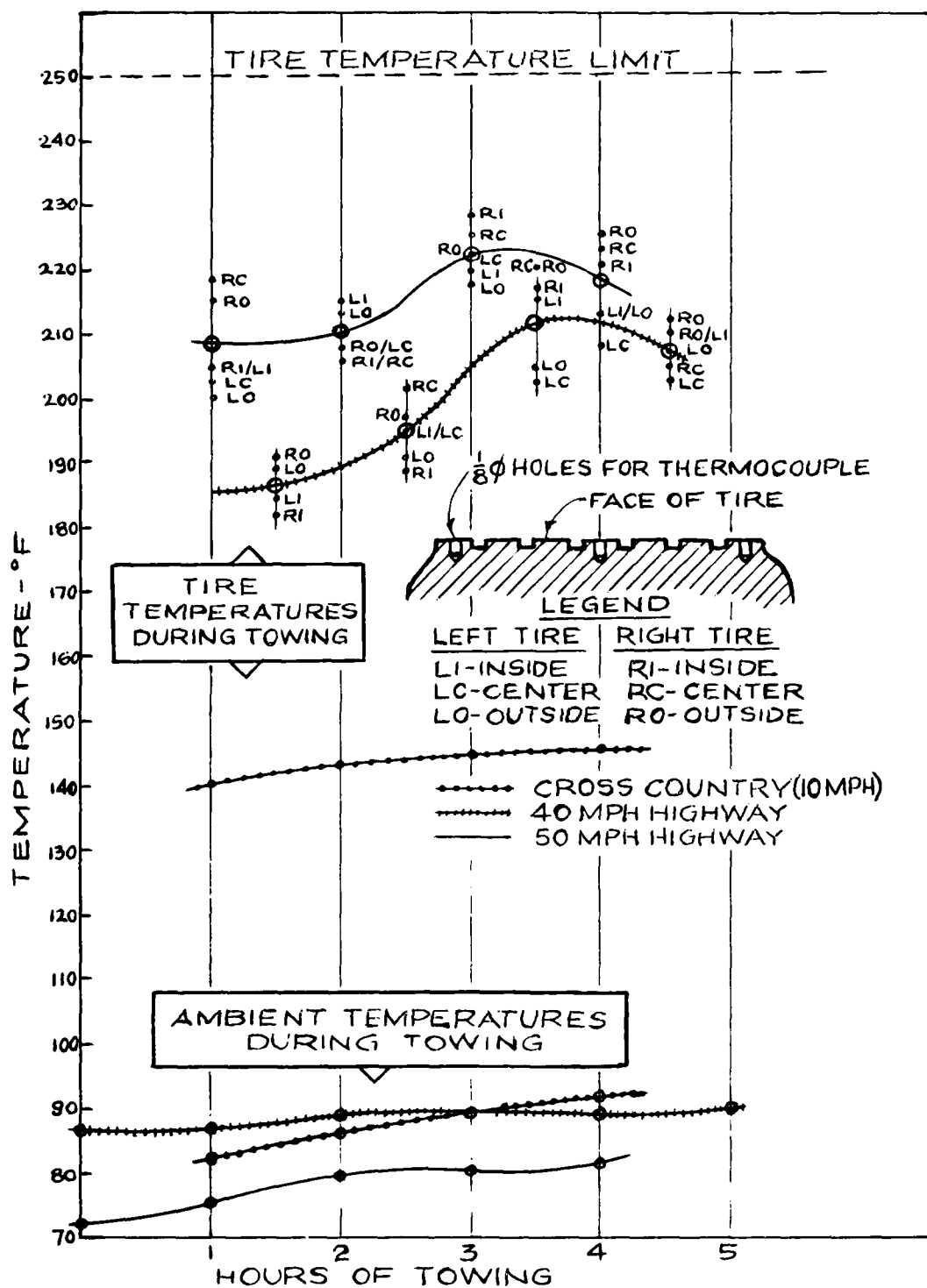


Figure 23. Narrow tire temperature tests

ALTERNATIVE PINTLE ASSEMBLY No. 1

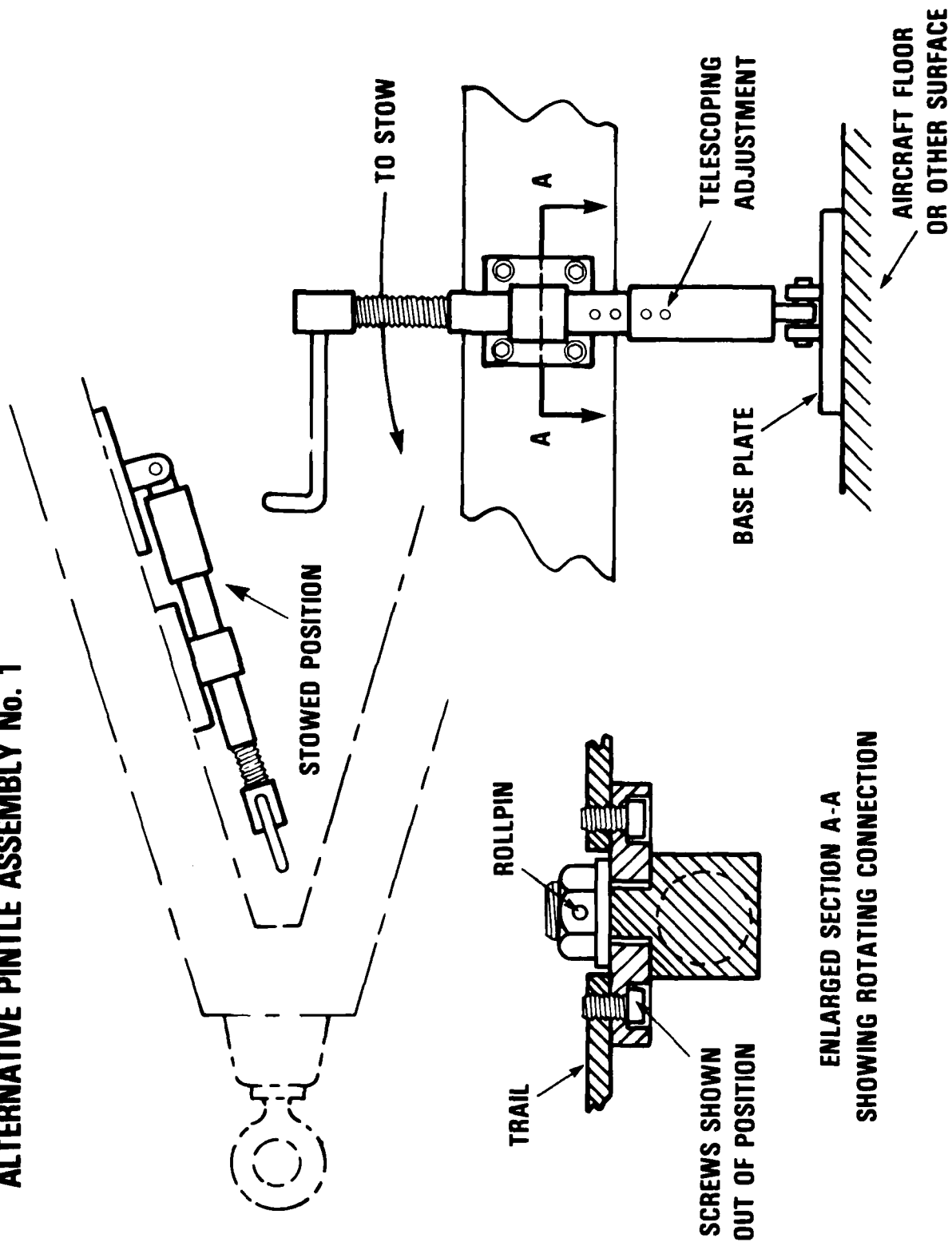


Figure 24. Alternative jacking system No. 1

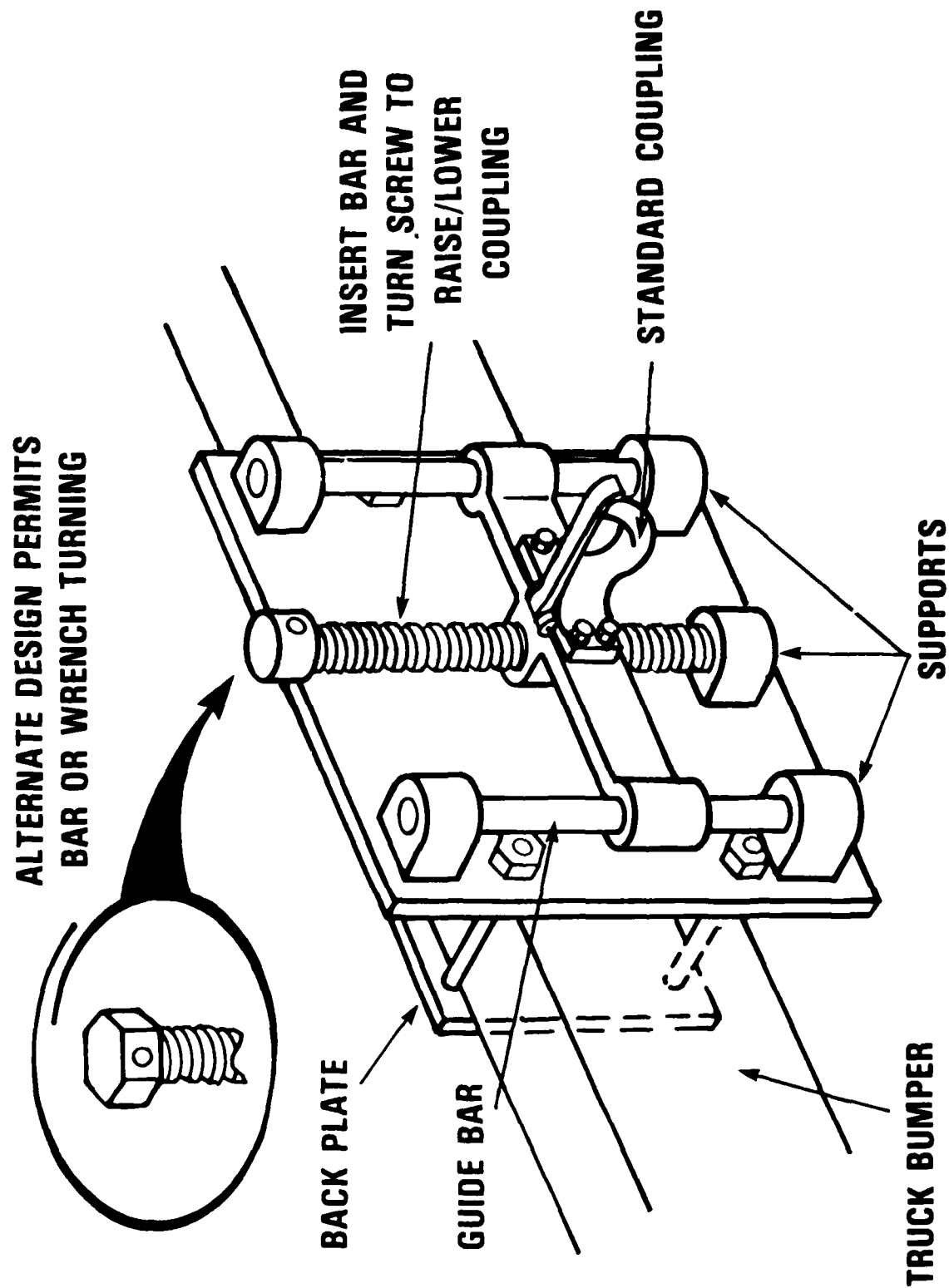


Figure 25. Alternative jacking system No. 2

LOADING/STOWING PROCEDURE

- 1-HOWITZER IS PUSHED INTO CARGO PLANE BY MEANS OF 2 1/2 TON TRUCK WITH FRONT-BUMPER-MOUNTED PINTLE AND POSITIONED PER MANUAL.
- 2-JACK IS POSITIONED UNDER LEFT SPACE BRACKET, AS ILLUSTRATED.
- 3-HANDWHEEL IS CRANKED UNTIL LUNETTE IS RAISED HIGH ENOUGH TO CLEAR THE BOTTOM PLATE OF THE PINTLE ASSEMBLY.
- 4-LUNETTE PIN IS REMOVED.
- 5-TRUCK IS BACKED OUT OF AIRPLANE.
- 6-HANDWHEEL IS CRANKED UNTIL YOKE IS RESTING ON TOP OF ACTUATOR.
- 7-HOWITZER IS SECURED TO AIRPLANE, READY FOR FLIGHT.
- 8-DIAMOND HATCHED AREAS REPRESENT M198 HOWITZER.

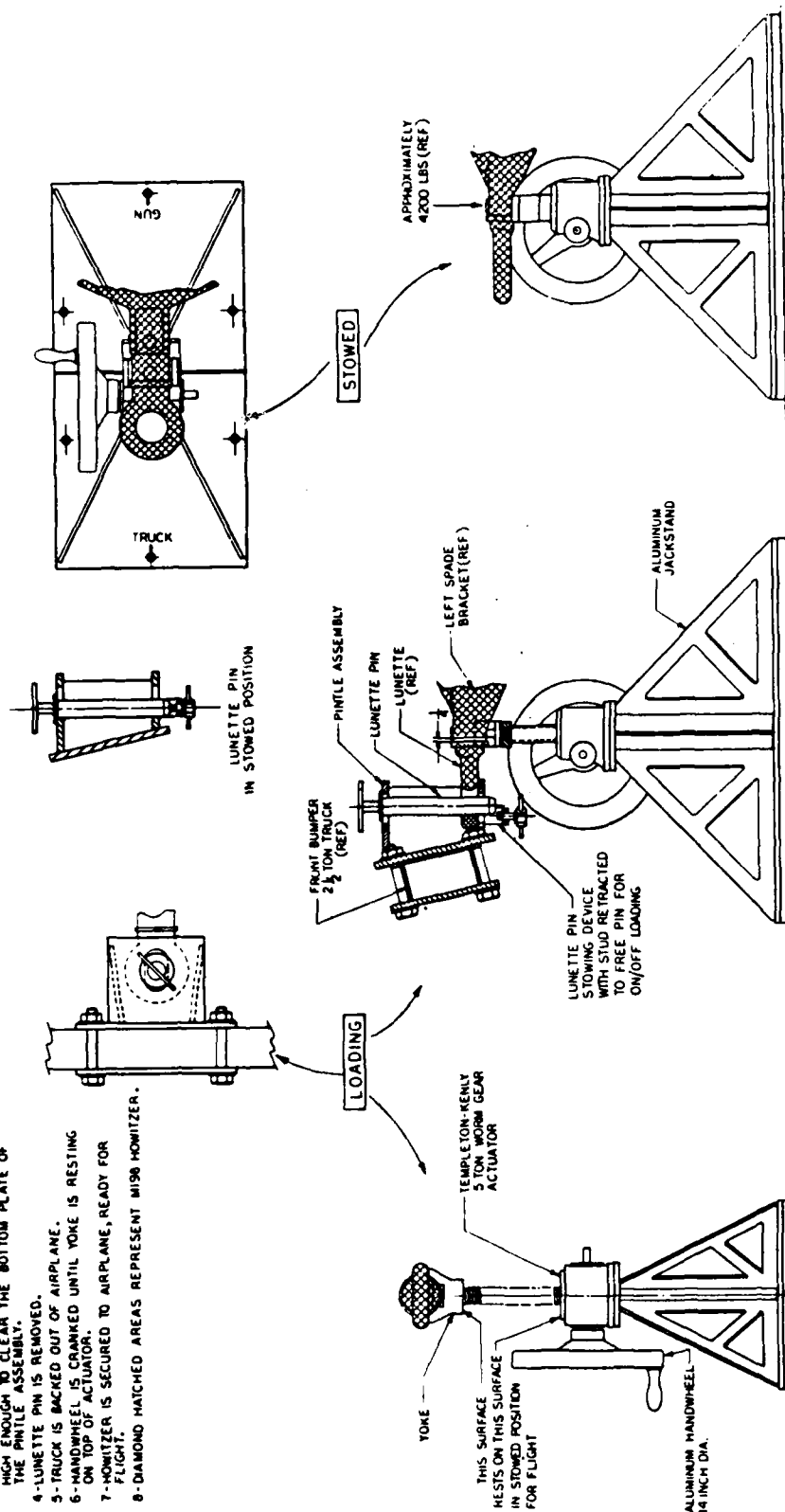


Figure 26. Improved jacking system and pintle assembly



Figure 27. Improved jacking system being used to separate gun from truck

USED IN IMPROVED JACKING PROCEDURE FOR LOADING M198 HOWITZER IN CARGO PLANES

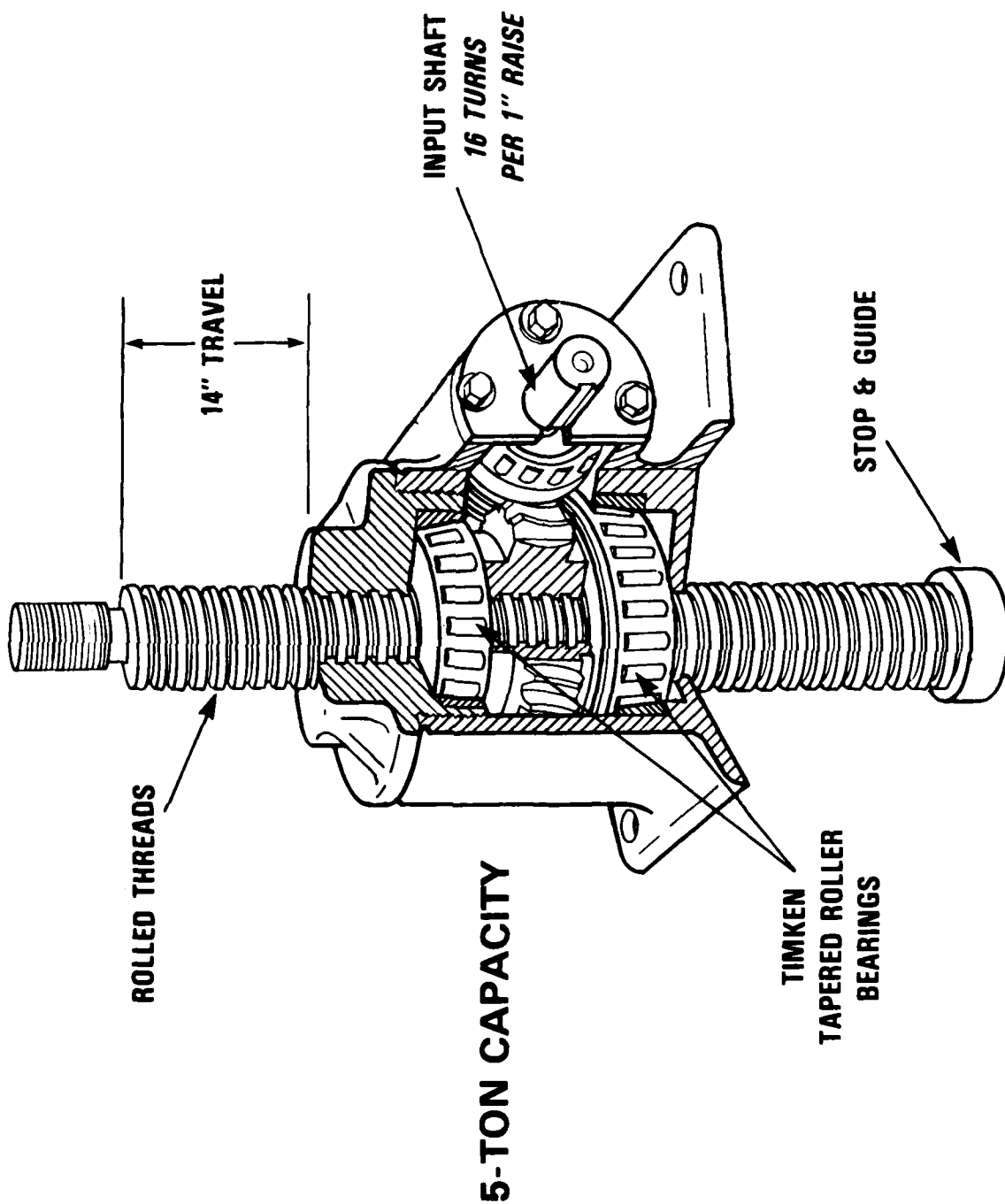


Figure 28. Worm gear actuator used in improved jacking system

**DRAWING DEPICTS ATTITUDE OF PINTLE ASSEMBLY
WITH RESPECT TO JACK AND GUN WHEN GUN IS IN AIRPLANE**

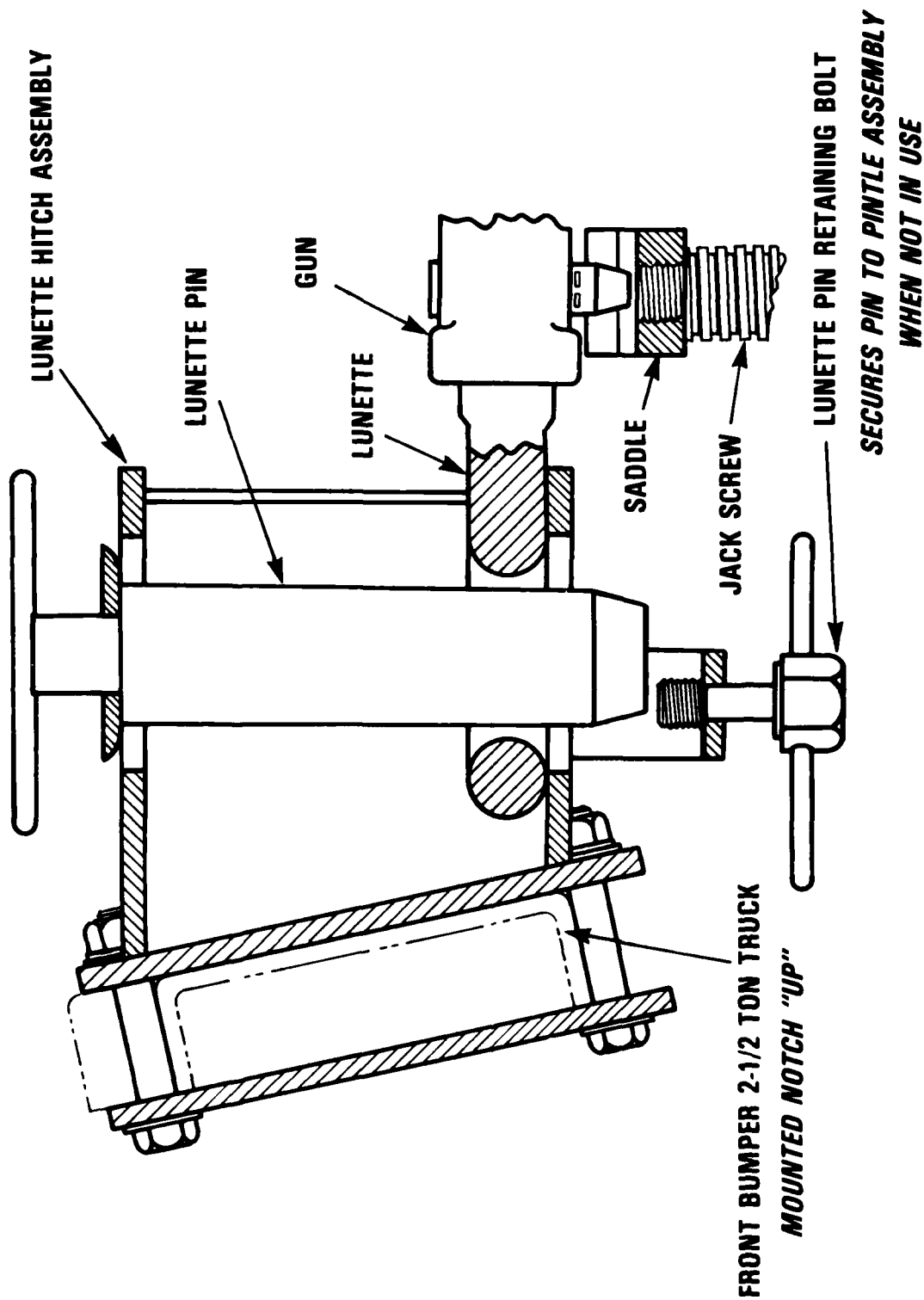


Figure 29. Improved front bumper pintle assembly

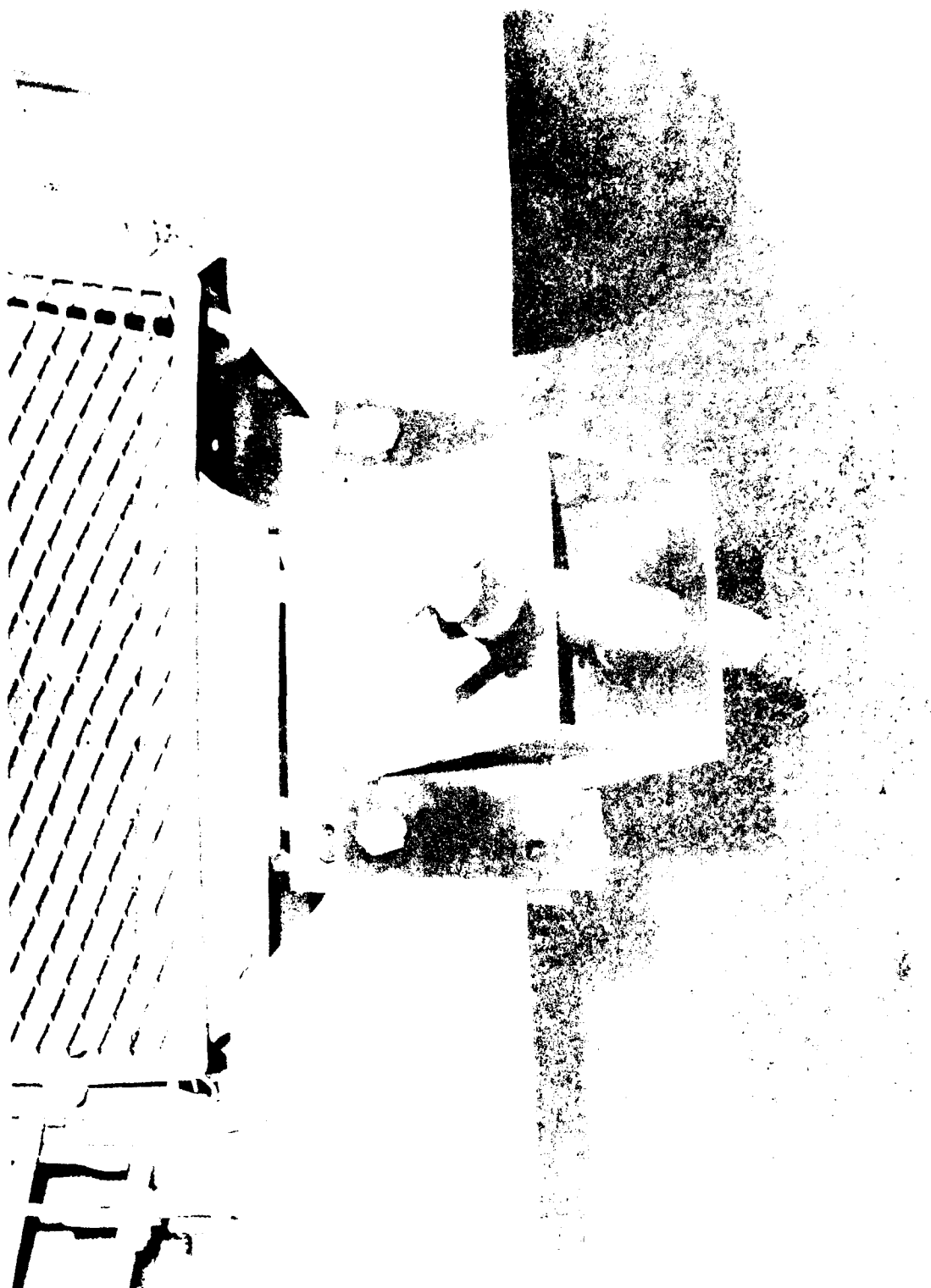


Figure 30. Improved pintle assembly mounted on front bumper of truck

AIR TRANSPORT OF M198 HOWITZER BY CARGO PLANE **ON-LOADING PROCEDURE** **USING IMPROVED JACKING & PINTLE ASSEMBLY**

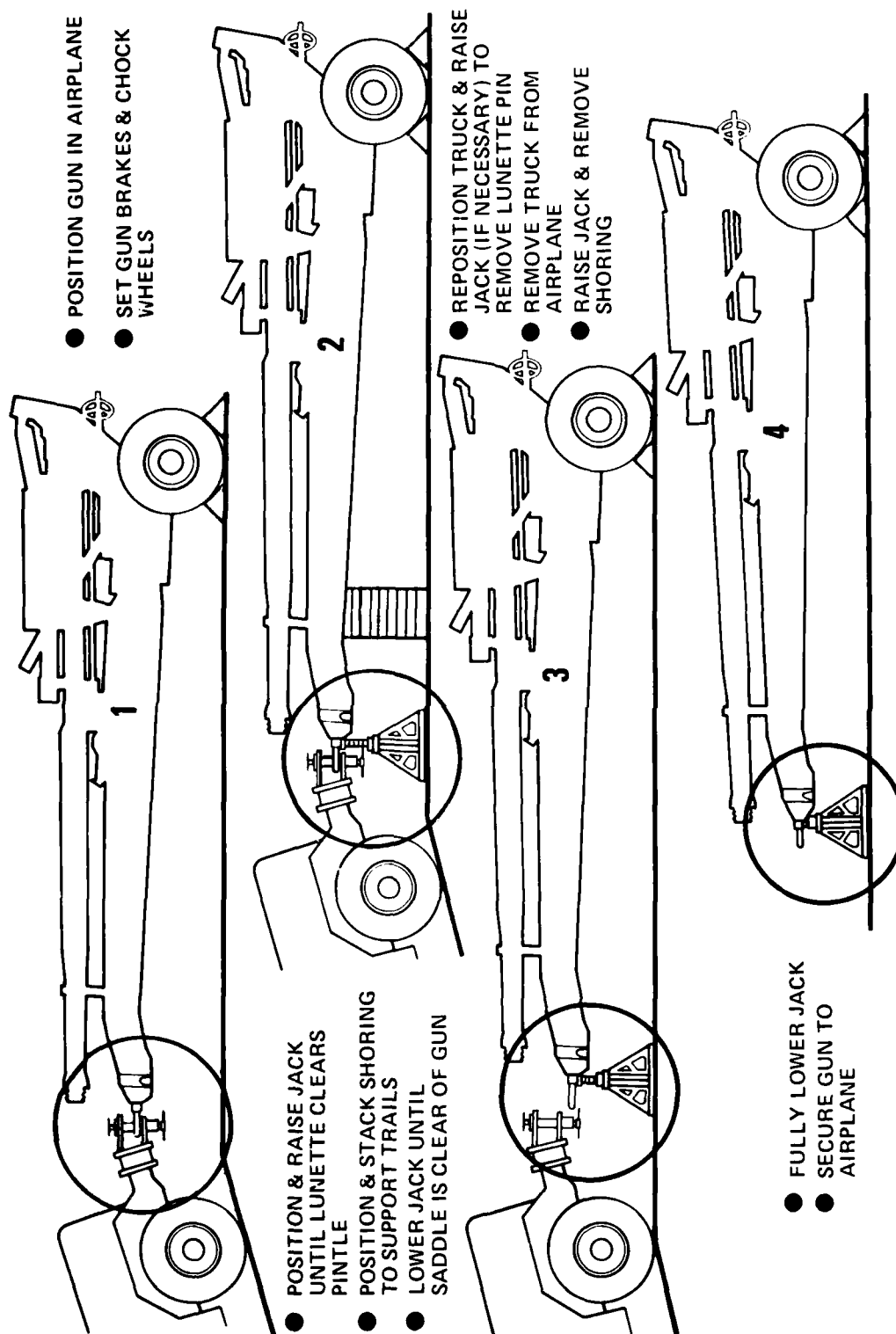


Figure 31. Loading procedure using improved jacking system and pintle assembly

AIR TRANSPORT OF M198 HOWITZER BY CARGO PLANE **OFF-LOADING PROCEDURE** **USING IMPROVED JACKING & PINTLE ASSEMBLY**

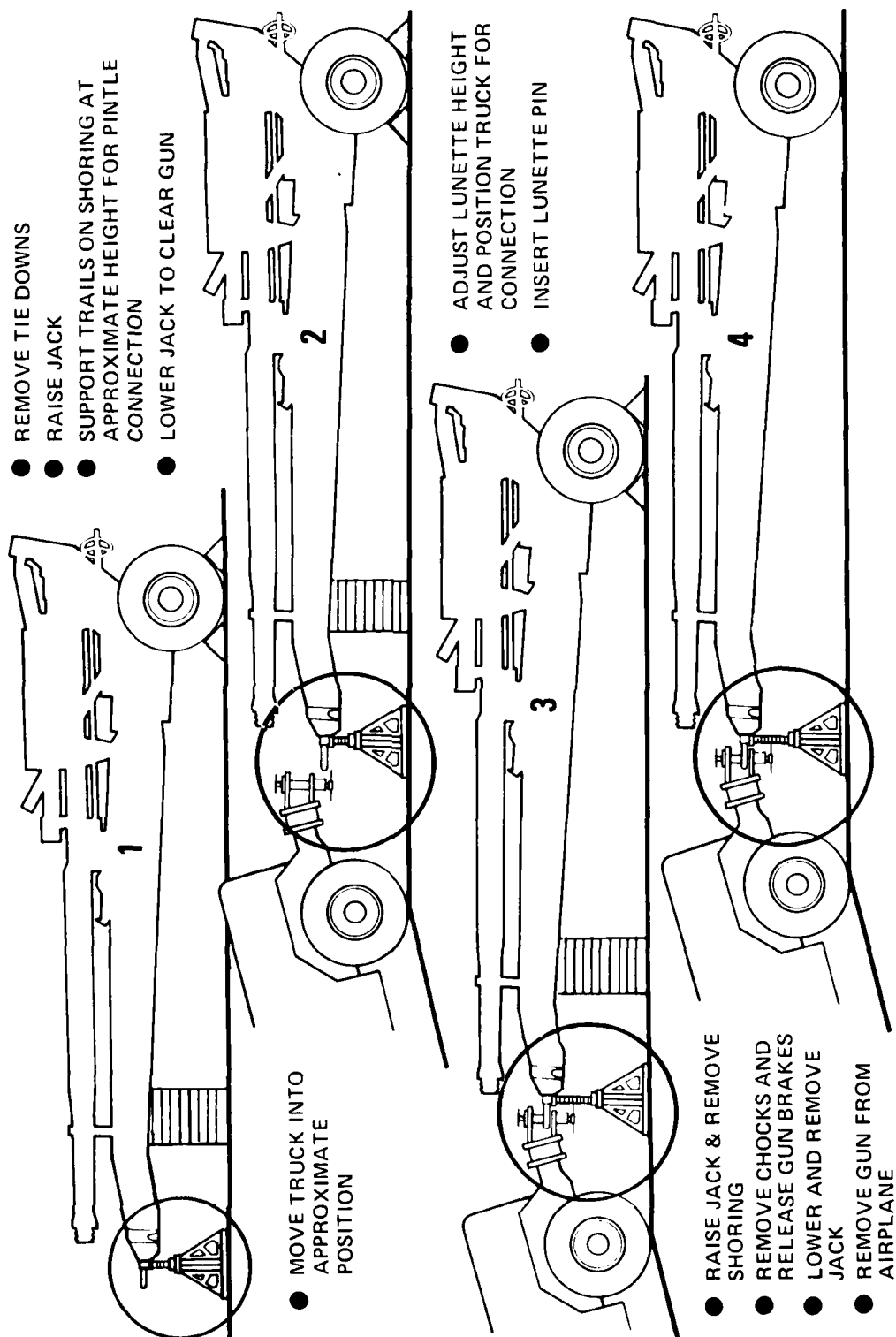


Figure 32. Off-loading procedure using improved jacking system and pintle assembly

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8. Goodyear Engineering Bulletin 80-2, August 28, 1980.
9. "Special Study of 155-mm M198 Towed Howitzer, Narrow Wheel/Tire Assembly, Final Report," TECOM Project No. 2-WE-200-198-044, APG Report No. APG-MT-6034, June 1984.
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APPENDIX A

TRANSPORT OF THE M198 HOWITZER IN THE C-130 AIRCRAFT

by

Marvin H. Linn
5 July 1977

1. MAC has promised approval of a procedure for transport of the M198 howitzer in the C-130 aircraft. This procedure, as now constituted, will require approximately 1000 board feet of lumber to shore above the fixed outer rails of the -4A cargo rail system on the treadway of the C-130 aircraft. The M198 howitzer must be pushed onto the C-130 aircraft (and pulled off) using an M35 2 1/2-ton cargo truck (the front axle load must be under 13,000 lb) with a pintle device using the 3-ton hydraulic jack from the M35 truck. Next, the M198 howitzer trails are lowered to shoring spanning between the shoring on each treadway.

2. A potential procedure has been developed, but not tested, which will eliminate the treadway shoring and the need for the use of the M35 2 1/2 ton cargo truck. In this case, the outer rails for the -4A cargo rail system are removed to the first joint inside the C-130 aircraft past the rear side door, as for paratroop operations. The inboard cargo rails remain and two HCU-6/E (7 ft 4 in. x 9 ft 0 in.) cargo pallets are married together and positioned inside the top of the 10-ft-long ramp. The M813 5-ton cargo truck prime mover then pushes the M198 howitzer up the ramp onto the pallets (some blocking required), and 7 ft 4 in. into the C-130 aircraft. A spreader beam device (approximately 150 lb/sq ft, 6,000 lb on each pallet) is positioned under the M39 carriage of the M198 howitzer. The M39 carriage is lowered onto the spreader beam structure and the road arms of the suspension system are raised. The M813 truck then pushes the M198 howitzer forward (approximately 145 in.) into the C-130 aircraft until the end of the trails are over the end of the 10-ft-long ramp. The C-130 loadmaster will then call for another standard pallet and sufficient shoring (150 lb/sq ft) to support the 4,000-lb trail load. When this is in place it is anticipated that the hydraulic system, normally used to raise the ramp and up to 5,000 lb load thereon, can readily and very quickly raise the M198 howitzer lunette from the pintle device on the front bumper of the M813 prime mover. When the ramp is level, the M198 howitzer is hand pushed (the aircraft winch could be used) forward approximately 10 ft and tied down for flight. The procedure is reversed for towout by the M813 prime mover at destination.

3. The second procedure is a must if the C-130 aircraft stays balanced when the ramp is raised with the M198 howitzer's trails on it. The first procedure will work, but only one M35 cargo truck with winch is available in each battery of the Army, and the Marines have none. No one has 1,000 board feet of lumber readily available with each howitzer and the hydraulic jack operation is excessively time consuming. If C-130 aircraft balance is reasonably close, then the addition of a forward load of ammo on a standard cargo pallet should provide the success factor.

APPENDIX B

SUMMARY OF TROOP RESPONSES TO QUESTIONS

CONCERNING MOBILITY COMPARISON TESTS

CHART 3. SUMMARY OF RESPONSES TO MOBILITY COMPARISON DATA FORMS

QUESTION	PERCENTAGE OF RESPONSES		
1. With which wheel/tire was it easier to tow an M198 over:	<u>Narrow</u>	<u>Wide</u>	
a. Primary roads	95%	5%	
b. Secondary roads	100%	0%	
c. Cross country	90%	10%	
d. Soft soil (mud and sand)	90%	10%	
2. With which wheel/tire was it safer to tow an M198 at maximum allowed speed over:	<u>Narrow</u>	<u>Wide</u>	<u>No Difference</u>
a. Primary roads	45%	0%	55%
b. Secondary roads	29%	0%	71%
c. Cross country	48%	4%	48%
d. Soft soil (mud and sand)	48%	10%	42%
3. Which wheel/tire provided the greater mobility over:	<u>Narrow</u>	<u>Wide</u>	<u>No Difference</u>
a. Primary roads	48%	9%	43%
b. Secondary roads	67%	4%	29%
c. Cross country	71%	5%	24%
d. Soft soil (mud and sand)	76%	14%	10%
4. With which wheel/tire was it easier to pull an M198 over:	<u>Narrow</u>	<u>Wide</u>	<u>No Difference</u>
a. Primary roads	48%	4%	48%
b. Secondary roads	67%	8%	25%
c. Cross country	67%	4%	29%
d. Soft soil (mud and sand)	76%	14%	10%
5. With which wheel/tire was it easier to turn an M198 over:	<u>Narrow</u>	<u>Wide</u>	<u>No Difference</u>
a. Primary roads	50%	5%	45%
b. Secondary roads	57%	0%	43%
c. Cross country	48%	4%	48%
d. Soft soil (mud and sand)	45%	5%	50%

QUESTIONPERCENTAGE OF RESPONSES

6. With which wheel/tire did the M198 weave the most over:

	<u>Narrow</u>	<u>Wide</u>	<u>No Difference</u>
a. Primary roads	0%	38%	62%
b. Secondary roads	4%	48%	48%
c. Cross country	9%	43%	48%
d. Soft soil (mud and sand)	4%	48%	48%

7. With which wheel/tire did the M198 bounce the most over:

	<u>Narrow</u>	<u>Wide</u>	<u>No Difference</u>
a. Primary roads	5%	76%	19%
b. Secondary roads	0%	86%	14%
c. Cross country	0%	86%	14%
d. Soft soil (mud and sand)	9%	67%	24%

8. Which wheel/tire did you prefer when towing the M198 over:

	<u>Narrow</u>	<u>Wide</u>	<u>No Difference</u>
a. Primary roads	86%	0%	14%
b. Secondary roads	86%	0%	14%
c. Cross country	86%	9%	5%
d. Soft soil (mud and sand)	80%	10%	10%

9. If you had your choice, which wheel/tire would you use:

<u>Narrow</u>	<u>Wide</u>	<u>No Difference</u>
85%	5%	10%

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