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AN EVALUATION OF THE COUPLED LVT CONCEPT

by:

Irmin O. Kamm
Peter W. Brown
Peter M. Brady, Jr.

Prepared for:

David Taylor Naval Ship Research
and Development Center
Code 112
Bethesda, MD 20084

Under:

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CASTLE POINT STATION
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The feasibility of coupling a pair of amphibious tracked vehicles has been studied, with the objective of improving the land and water performance.

Recommendations are made for a coupling system and its controls and for an articulated configuration. The advantages in land and water performance, as well as the drawbacks, are presented in comparison to single vehicles.

The advantages exceed the drawbacks, it is recommended that existing vehicles be coupled and tested to establish their operational capability.

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Coupling Systems	Off-road Mobility
Control Systems	Vehicle Performance
Articulated Vehicles	Military Vehicles
Hydrodynamic Performance	Sea Keeping

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1.1 EXECUTIVE SUMMARY

Basic Study: The Davidson Laboratory, Stevens Institute of Technology, has completed a study to explore the feasibility and potential gains in land and water performance that can be expected by tandem "coupling" of two identical amphibious landing vehicle assault craft without compromising their performance when decoupled to again become single vehicles. In addition, a brief study was also made of the feasibility of "articulated" amphibious vehicles, a concept similar to a tractor-trailer system wherein the lead unit contains the engine and drive mechanisms and the rear unit contains the troops, armament, etc.

History of Coupled Vehicles: It is shown that coupling pairs of vehicles has long been recognized as a means for improving their cross-country mobility. They have found acceptance by both commercial users in exploring isolated areas in Canada and the Alaskan North Slope and by the military where superior surface mobility was required in snow and ice environments. Since coupled vehicles also appear to have improved performance in calm and rough water, it was natural for the U.S. Marine Corps to consider tieir potential in the search for improved amphibious assault landing craft.

Coupling Systems: The present study considers coupling systems varying in capability from a simple unpowered ball joint to a powered cone-socket coupler where relative pitch ($\pm 30^{\circ}$) and relative yaw ($\pm 30^{\circ}$) between vehicles can be controlled while maintaining relative roll freedom. It is concluded that this later concept, which consists of a cone socket in the bow of the rear unit and a penetrating cone in the stern of the forward unit, is most attractive for the following reasons; it has the minimum system weight of all actively coupled concepts (approximately 3800 lbs. for an LVTP-7 vehicle); it is easily remotely uncoupled on land and in water; it is easily remotely coupled on land with the potential of remote coupling in calm water and in beam seas; it has optimum location of the pitch and yaw axis; it has a minimum intrusion into the stern ramp; it preserves the cargo hatch; it does not compromise the performance of each unit as a separate vehicle; each vehicle shares in the power supplied to the joint; it allows each vehicle to be identically equipped so that they can be either a front or rear unit as necessary. It is expected that there will be drivers available in both vehicles, although, when coupled, control will be by the driver in the forward or master unit.

Controls: Pitch and yaw control can be obtained by means of hydraulic cylinders located in both vehicles. A pump in the forward vehicle (powered by its main engine) operates the pitch cylinder while a pump in the rear vehicle operates the yaw cylinder.

Both engines in the coupled vehicles will be operated in concert and synchronized. This can be accomplished by using a servo-actuator on the rear engine which is slaved to the mechanical controls on the forward engine. Any failure in the electrical system will immediately engage the mechanical controls on the rear engine which can then be operated by the driver in that vehicle.

Remote transmission controls are not warranted since the driver in the slave vehicle can, by voice command from the master vehicle, set the required transmission range.

Braking of the coupled units can be done within the transmission, resorting to power down-shifting if necessary.

The controls for steering and pitch actuation are placed with the driver in the master unit. Either a "joy-stick" or a steering wheel control can be selected to activate the hydraulic control cylinders.

Expected Land Performance for Coupled Vehicles: To illustrate the land performance of coupled amphibians, a study was made of the potential gains in performance for coupled LVTP-7 vehicles as compared with a single LVTP-7. These results are:

1. Increase in the negotiable obstacle height from 3 ft. to 7 ft.
2. Increase in trench width crossing from 8 ft. to 14 ft.
3. Increase in short slope negotiation from 39% to 100%.
4. Water exit on slopes up to 67%. (Maximum exit slopes for single LVTP-7 are not presently available).
5. Approximately a 75% increase in speed for a cross-country ride at 6 watts absorbed power.
6. Get-home capability if one of the coupled vehicles is disabled.
7. More efficient power transmission in steering.

8. Better performance and steering in marginal terrain.

Some of the disadvantages associated with coupling are listed below:

1. Larger turning radius (no pivot turns).
2. Increased target size.
3. Additional hardware and controls results in an increase in:
   weight
   internal occupied space
   cost
   maintenance and driver training

Expected Water Performance for Coupled Vehicles: Compared to a single LVTP-7, it is expected that the following gains in water performance will be achieved by coupling the forward vehicle to have a 15° pitch incidence relative to the rear vehicle.

1. The calm water drag of the coupled vehicle, on a per ton basis, is 75% that of a single vehicle.

2. There is substantial nose-diving of a single vehicle at speeds in excess of approximately 7 mph. The coupled vehicle shows a continuous increase in bow trim with speeds in excess of 7 mph with no tendency to bury the bow at intermediate speeds.

3. Since coupled vehicles reduce the calm-water drag and eliminate bow burying, speed improvements of nearly 4 mph are possible depending upon the installed power. Such speed improvement could not be obtained with the existing LVTP-7, no matter what the power, because of extensive water over the bow.

4. In head seas of 2.2 ft., significant wave height (Sea State 2), the coupled vehicle can operate at 10 mph whereas the single vehicle is limited to speeds of about 6 mph.

5. The acceleration of the coupled vehicles in Sea State 2 attains their maximum values at a speed of 8 mph. The RMS acceleration is only 0.08g and the average of the 1/10-highest peak acceleration is 0.2g at the C.G. of the forward vehicle. The accelerations in

the single and coupled vehicles are similar, but the pitch motions of the coupled vehicles are nearly 50% less in the 4 to 6 mph speed range.

6. Either configuration has accelerations well below the one-hour exposure "fatigue decreased proficiency" limit recommended by the International Standards Organization, and both are below even the ISO two-hour exposure limit.

Performance of Articulated Vehicles: The articulated vehicle is a multi-unit vehicle which is designed to operate in unison at all times and under all conditions. A viable concept which has been developed in this study consists of a forward section containing the main power plant and transmission and, possibly, also containing automatic armament and ammunition. The rear unit contains all personnel, including the driver, and an auxiliary engine. The articulation joint with powered pitch and yaw articulation and freedom in roll is contained in a sealed enclosure. The overall length of the vehicle is 33 ft. (14 ft. forward section and 19 ft. aft section), the gross weight is estimated to be 54,000 lbs. and there is only one main engine of 890 GHP which is controlled by the driver. Steering and pitch control are by either joy-stick or steering wheel directly to the hydraulics actuating the joint.

The expected performance of an articulated vehicle, compared to a single LVTP-7, is:

1. Step obstacle height of 4 ft. compared to 3 ft.
2. Trench width crossing of 14 ft. compared to 8 ft.
3. Negotiates a 58% short slope in soft soil compared to 39% for a single vehicle.
4. Can water exit on a slope of 67%.
5. Cross-country speed increased nearly 75% for 6-watt ride.
6. Turning radius 35 ft. compared to 15 ft. for single vehicle.
7. Since model tests were not performed, estimates of the water performance are not available, although they are expected to substantially exceed those of a single LVTP-7.

2.1 CONCLUSIONS

Based on the results of the present study, it is concluded that either coupled or articulated amphibious assault landing vehicles are feasible and can easily be adapted to existing landing craft and/or new designs. The expected improvement in land and water-borne performance are impressive and are judged to outweigh those disadvantages associated with coupled units.

2.2 RECOMMENDATIONS

Design, fabricate, and install a suitable coupling system which will allow a bow-to-stern attachment of two LVTP-7 (or LVTPX-12) vehicles.

Conduct tests on land, in water, and in surf to demonstrate the expected advantages of coupling and to provide operational evaluation and experience related to coupled amphibious vehicles.

3.1 INTRODUCTION

The Davidson Laboratory of Stevens Institute of Technology has been requested by DTNSRDC, Code 112, to explore the feasibility and gains in performance that can be made by coupling and articulating future Marine Corps Landing Vehicles. This is the first step towards the short range goal which is to demonstrate the added capabilities (and to measure such performance) with a test vehicle assembled from two contemporary vehicles. The longer range goal is to apply the practical and analytic knowledge gained to future vehicles to be developed by the Marine Corps.

3.2 BACKGROUND

The coupling of pairs of vehicles has long been recognized as a means of improving their cross-country (off-road) mobility (Reference 1). Reasons for this improvement in performance include the improved ability of the coupled vehicles to conform to the terrain, the inter-vehicle assist provided by active coupling and, for tracked vehicles, reduction in steering losses. Coupled vehicles have found acceptance where there has been a need for superior surface mobility by both commercial users (e.g., the "Muskox" and "Nodwell" vehicles used by oil companies in exploring isolated parts of Canada and on the Alaskan North Slope) and the military (e.g., the articulated tracked Snow Vehicle "BV 202" used by the Swedish Army, the U. S. Army M-561 and the Pole-Cats used on the Greenland Ice Cap).

The ability of coupled and articulated vehicles to negotiate terrain impassable to a comparable single vehicle has also been demonstrated by such prototype systems as the US/Canadian XM-571, the "Jeep Train" built for TRECOM, the MEXA Vehicles built for the U. S. Army, the "Twister" designed by Lockheed, and others. The additional improvement in mobility which can be achieved by articulated vehicles with active control of the pitch articulation has been demonstrated in experiments with the three-unit "Cobra" built by WNRE for the Land Locomotion Laboratory of the U. S. Army. Table 1 is a short historical overview of the characteristics of the more pertinent articulated vehicles.

The most recent research effort in the area of actively coupled vehicles was the Cybernetically Coupled Research Vehicle (CCRV) program (Reference 5). In this program, two existing tracked military vehicles were coupled with powered articulation which was controlled in pitch and yaw by a single joy stick incorporating force feedback. The vehicles used were M-113-A1 Armored Personnel Carriers, selected to demonstrate the feasibility of retrofitting this special-purpose system onto existing hardware and to allow a direct comparison of the performance of a single unit with that of the coupled system. The CCRV was shown to be superior to the single M-113 in cross country ride, soft soil maneuverability and water speed, and far superior in vertical obstacle negotiation, trench crossing ability, and water egress capability.

Much of the knowledge and experience gained with this vehicle can now be applied directly to tracked amphibious landing craft. However, the prior studies centered on performance on land, so little data is available on the effects of articulation in water. It is the purpose of this study to explore the operational feasibility of coupling two standard U. S. Marine Corps amphibious tracked landing vehicles and to validate techniques to predict the expected performance of future coupled or articulated vehicles operating on land and in water.

3.3 OBJECTIVES

The objectives of this program are:

1. Explore, by use of scale models, the gains that can be made in water performance by vehicle coupling.
2. Estimate the land performance of coupled vehicles using an extension of existing analysis methods and comparisons with known vehicles.

3. Develop coupling concepts which are suitable for the U.S. Marine Corps mission which can both be demonstrated for the near term and be compatible with contemplated future vehicle developments.

4. Investigate two groups of concept: that of vehicles which primarily operate as single vehicles but can be coupled when necessary and that of a multi-unit arrangement which always operates as a single articulated vehicle.

4. CONSTRAINTS AND ASSUMPTIONS

The preservation of the existing operational capabilities of the vehicles impose certain constraints on the coupling systems. In addition, there are assumptions that can be made based on the expected use of the coupled vehicle. These constraints and assumptions are not necessarily the same for both the coupled and the articulated concepts.

For the purpose of this study, the term "Coupled Vehicles" means two or more individual vehicles which are optimized for operation as single units but can be coupled together when operational conditions or mobility requirements dictate it. By contrast, an "Articulated Vehicle" is one designed to operate as one multi-unit vehicle at all times under all conditions; it should only be broken apart for ease of transport, for marriage with another mate of different capabilities (wreckers, cargo carriers, tankers, etc.) or for survival when the other unit has been catastrophically disabled.

The constraints and assumptions used in the development of the concept will be:

For the Coupled Vehicles:

1. Preserve the rear ramp and emergency exits.
2. Preserve the cargo hatch.
3. Be able to uncouple both on land and on water.
4. Assume there will be a co-driver/monitor in the slave unit.
5. Equip all vehicles identically so that they can be either a front or a rear unit, interchangeably.
6. Preserve individual vehicle capabilities unimpaired.

For the Articulated Vehicle:

1. Do not exceed 33 ft in overall length.
2. Have an exit ramp for the troop compartment.
3. Have a top cargo hatch for the troop compartment.

4. Have an emergency disconnect capability, with either unit capable of limited individual operation.

5. Have only one driver.

5.1 CONCEPT DESIGN AND ANALYSIS

The investigation started with the layout of a series of general concept ideas for the coupling of individual vehicles. The seemingly arduous development of the concepts served the purpose of providing the necessary basic configurations and information as input to the hydrodynamic scale model test program, to the land performance evaluation and to the comparison with known vehicles. These concepts progressed from the simplest coupling arrangement with limited capabilities to the more complex, as the detailed requirements became more clearly defined. The progression of the coupled concepts is shown in Figures 1 through 12. The feedback from model experiments and mobility analysis placed emphasis on the later concept versions, in order to realize the full potential of the improvements possible in both land and water performance. Using the primary evaluation factors in Table II discussed below, concept #12, shown in Figure 12, was selected as the one which best combines most of the desirable features with minimum complexity, space, weight and cost.

The primary factors used in the evaluation of each concept layout are listed in Table II. They are based on the following arguments:

RANGE OF MOTION: Experience with existing coupled and articulated vehicles, and the results of the model studies, show that the following degrees of freedom in the joint are necessary to perform the required functions of the vehicle.

Yaw articulation control is necessary for vehicle directional control. In its simplest form it is the type of steering that almost all front end loaders use. The military Goer vehicles are also an example of simple yaw steering. Yaw articulation of multi-unit tracked vehicles permits the use of an effectively long vehicle (desirable for mobility) which can still be steered. Tracked single-frame vehicles which have a ground contact length to tread spacing (L/T) ratio in excess of about 2 to 1 are impossible to steer. It is expected that yaw control will also be beneficial in steering the craft in the water-borne mode.

Pitch articulation freedom is necessary for the individual units to be able to conform to undulations in terrain and to negotiate obstacles. Controlling pitch attitude by powered articulation permits the crossing of obstacles not otherwise possible, and produces all the advantages of a long vehicle for ditch crossing and cross country ride. In the water-borne mode, pitch articulation is most beneficial in reducing hydrodynamic drag and improving visibility.

Roll freedom is necessary to distribute the ground pressure under the suspension elements relatively evenly. Experience shows no need for this motion to be powered and controlled. In the water-borne mode, roll freedom allows the coupled system easily to adjust to the irregular wave forms, particularly in oblique seas.

POWER SUPPLY: The power for the articulation should be generated by the engine of the vehicle on which the joint actuation hardware is mounted, in order to minimize power transmission problems.

Hydraulic or electric systems and their combinations with mechanical components are all possible candidates for transmission of power. Should the coupling be configured such that each vehicle carries part of the system then each vehicle will power that component which it carries.

CONTROLS: The preferred location for the control station is in the forward vehicle, for best visibility. For certain operations the control from the rear may be of advantage, as when coupling the vehicles. Transmission of the control command and feedback signals from one vehicle to the other involves only the risk of the electrical inter-vehicle signal connection. All controls must be fail-safe to prevent run-away vehicles and in the sense that limited, or manually controlled, operation is still possible if the inter-connect system fails.

REMOTE COUPLING AND UNCOUPLING: This is considered to be an essential requirement for a combat vehicle. Coupled vehicles are intended to operate primarily as a single vehicle and should be coupled only when the operational requirement dictates it. Subsequently, they are to be uncoupled again and operate as single vehicles. Any coupling concept that requires the manual assistance for coupling or uncoupling from outside of the vehicle is considered to be unacceptable.

INTERFERENCES WITH EXISTING VEHICLE FEATURES: Vehicle features essential for its mission should not be interfered with. Such features include the stern ramp, cargo hatches, personnel exits, and armament. Its mobility as a single unit, its propulsion elements, angles of approach and departure, ground clearance and pivot turn clearance should not be compromised.

SPECIAL STRUCTURE REQUIRED: Special vehicle structure other than that of the coupling joint itself, will be necessary in the adaptation of an existing vehicle. This probably would not be necessary in the development of a new vehicle with coupling in mind at the start of the design.

GRAVITATION COMPONENTS: The best location for the yaw axis and that for the pitch axis do not coincide. For the best steering efficiency, the yaw axis should be at the midpoint between the geometric center of the tracks of the front and rear units (this is usually also close to the midpoint between the two centers of gravity). For best obstacle crossing capability, the pitch axis should be as close to the leading unit as possible in order to produce the maximum possible pitch-up attitude of the leading unit for a given inter-vehicle pitch angle.

FORCE LIMITATION addresses the possibility that a coupling concept may be limited in the force that can be transmitted by the joint by reason of its inherent design, not because of the size chosen.

WEIGHT DISTRIBUTION: The added weight of the coupling system and its location on the vehicle will affect the weight distribution. Excess weight in the bow produces undesirable effects in the hydrodynamic performance of the single vehicle. A large unbalance in either the front or rear, will make coupling difficult, if not impossible in water.

VULNERABILITY pertains to the added components and their assemblies. Exposed components are obviously less desirable than a location which is protected within the hull.

5.1.1 Coupled Vehicles

Concept 1 does not provide any powered articulation, it simply couples the vehicles such as to allow an inter-vehicle assist.

Concepts 2 and 3 provide powered yaw articulation only, with a 2 and 3 point connection not suitable for remote coupling.

Concepts 4 and 5 provide powered yaw and pitch control, with a three point connection. Concept 4 has independent yaw and pitch, in concept 5 the two cylinders provide both pitch and yaw, if they are contracted and extended in unison the vehicles pitch, if one is contracted while the other is extended the vehicles steer. Combinations of yaw and pitch are possible within the limits of the geometry.

Concept 6 is based on the same layout as Concept 5 but has a mounting frame added so that the vehicles can be coupled remotely.

Concept 7 is an attempt to provide yaw articulation at a minimum effort. Since there is no roll freedom it is doubtful that the hardware could survive the stresses induced by the roll-motion between vehicles.

Concept 8 provides for pitch control only, yaw control is provided by track steering. This system is of advantage only for simple obstacle crossing and for pitch attitude control to improve hydrodynamic performance.

Concept 9 utilizes an off-the-shelf turntable assembly normally used for cranes and backhoes for the yaw articulation joint. It is cheap, relatively light, can be driven by electromechanical means, and distributes the load on the vehicle. Pitch articulation is effected with a separate cylinder. The coupler, of conical shape for ease of connecting, provides the roll freedom. This arrangement is not yet optimum for remote coupling because the fixed receptacle is on the rear unit and the moveable parts are attached to the forward unit. Because the driver of the rear unit has the visibility to do the coupling-up, he would need to communicate to the driver in the forward unit how to make the position adjustments with the cone to match-up with the socket.

Concept 10: Mainly for the ease of coupling the fixed portion of the coupler has been located on the forward unit. Now the rear driver has all the controls to position both the vehicle and the coupler for a match-up. Pitch and yaw are controlled by the same two cylinders. The pitch pivot is the lower section of the bow. The yaw motion is about the vertical trunnion axis. The overriding negative aspects of this concept are that:

1. Most of the weight is placed in the bow of the vehicle, which is unacceptable for water operation as a single unit, and

2. The pitch axis is located too far to the rear of the combination which will result in lifting the rear a greater amount than the front; this is a poor attitude for obstacle negotiation.

Concept 11 is a repeat of the previous one but with all components moved below the deck line to reduce interference with driver visibility, at the expense of intruding in to the space of the rear ramp.

Concept 12 separates the location of the pitch and yaw axis and the actuation cylinders. The yaw axis is near the midpoint of the ground contact areas of the two units. The pitch axis is as far forward as possible for maximum pitch up attitude of the forward unit. The cone socket is contained in the yaw apparatus in the rear unit. The pitch cylinder acts directly on the cone without intermediate structure. In coupling, the rear driver has direct control over the yaw adjustment but not of the pitch attitude. The weight of the components is about equal in front and rear and most importantly, the hydraulic pumps and assorted components can be one-half the size in each unit. The pump in the forward unit supplies the pitch cylinder, the one in the rear the yaw cylinder. Thus, both pumps are working, whereas in all the other concepts, one pump is always idle.

The concept is shown with an intrusion into the stern ramp space, however, the height remaining is sufficient to drive a jeep through with the windshield lowered. The whole assembly can also be moved upward with a concommittant compromise in driver visibility.

All features considered, this concept combines the most attractive features, especially those of minimum system weight, power sharing of the two units, and optimal location of the pitch axis and yaw axis. It is therefore, considered a prime candidate for further consideration. The coupler is shown in detail in Section 5.1.3.

5.1.2 Articulated Vehicles

As the study progressed, it was expanded to include an articulated vehicle.

By definition, this is a multi-unit vehicle which is designed to operated in unison at all times, and under all conditions, it is only to be broken apart for transport or conceivably when a power unit is used in conjunction with special purpose working units. One very useful exception for a tactical vehicle may be the ability to jettison a disabled power unit and for the troop section to be able to reach cover under its own power.

Only one viable concept, with some minor variations, met all the constraints imposed on the design. It is shown as Concept 13. As depicted in Figure 13, it consists of a forward section containing the main power plant and transmission, possibly also automatic armament and ammunition. The rear section contains all personnel, including the driver, and the auxiliary engine.

Its tentative main characteristics are:

length, overall	33 ft
length, forward section	14 ft
length, rear section	19 ft
curb weight	54,000 lbs
weight, forward section	15,200 lbs
weight, rear section	38,800 lbs
ground contact pressure	6 psi
turning radius, vehicle clearance (wall to wall)	35 ft

The articulation joint with powered pitch and yaw, and roll freedom is contained in a sealed enclosure. The driveline passes through its center. The joint can be similar to one widely employed in contemporary articulated vehicles and schematically shown in Figure 14. The heavy load bearing structure is concentrated on either end of the joint. The track and suspension are simplified because the articulation permits variable geometry, especially of the angle of approach.

A conceptual powertrain is laid out in Figure 15, principally for the performance evaluation of Section 6.1. The 890 GHP main engine is coupled to a twin shaft powershift transmission. One shaft goes to the lead unit differential, the other through the articulation joints to the rear differential. Both differentials are open so that the speed of each track is free to conform to its turning radius, since steering is done by yaw articulation, with each track supplying the full tractive effort. The final drives for the front and rear unit are directly flanged to the joint structure for minimum weight.

The rear unit, which contains the troop compartment, has its own 100 HP auxiliary powerplant. This engine supplies the hydraulic power for steering and pitch control when articulated, and also to the two hydraulic motors in the rear section final drive when the troop section has to be self propelled. In addition, the auxiliary power plant supplies air conditioning and ventilation for CBR operation, and heat, electric and hydraulic power for stand-by use.

The water jets are driven mechanically from a power take off between main engine and transmission so that the tracks can be selectively disengaged. This places the water jets in the forward section which is less efficient than in the rear, but is offset by the weight savings in the driveline. Deflectors behind the water jets will move in conjunction with yaw articulation for optimum steering effort. Figure 16 shows the concept in the calculated floating attitude, additional bow up pitch attitude can be used for bow wave depression. It is recommended that hydrodynamic model tests be performed, to evaluate the water-borne performance of this unique concept.

The controls of the main engine and transmission, and conversely that of yaw and pitch, are either direct or remote depending on the location of the driver. The preferred location of the driver is in the rear unit for survivability, but in the forward unit he would have better visibility. Tactics, survivability and crew back-up are additional considerations. The configuration shown in Figure 13 shows all personnel contained in the rear unit.

The articulated vehicle can have three modes of operation:

1. Normal propulsion of both sections from the main engine, auxiliary power from the small engine in the rear unit.
2. Get home capability while experiencing a main powertrain failure; both units are connected and steered by articulation, the propulsive power is supplied by the auxiliary engine.
3. Emergency -- the forward unit is disabled and jettisoned; the rear unit with troop compartment is driven as a single track steered unit using the power from the auxiliary engine via hydraulic motors to each track.

The levels of performance that can be achieved in these three modes are presented and discussed in Section 6.1.2.

5.1.3 Quick Disconnect Coupling

A number of quick disconnect couplings were investigated during the progression of the coupled vehicle concepts. As Concept 12 emerged as the most advantageous combination, the exact design details for the coupling joint could also be defined better. Figure 17 shows the layout of the quick coupling joint as it is used schematically in Concept 12. The principal size and weight calculations are included as Appendix A. The cone, its support to the pitch joint, and the pitch hydraulic cylinder are attached to the stern of the forward unit. The socket, the yaw joint and the yaw cylinder are mounted in the bow of the rear unit. The cone is free to rotate in its socket to provide the freedom in roll. The joint, as laid out in Concept 12, provides for 30^{o} pitch-up, 30^{o} pitch-down and $\pm 30^{o}$ in yaw. The force exerted by the pitch actuator is directly applied between the vehicle structure and the cone structure. The yaw pivot is directly attached to the socket. The quick connect and disconnect function is performed by the series of balls arranged circumferentially to engage in the groove in the cone. The locking sleeve keeps the balls locked into the groove in the position shown. When the sleeve is slipped forward, the balls are free to disengage the cone. The locking sleeve is remotely actuated. Electrical (or fiber optics) connection for signal transmission and communications is made by a concentric ring connector in the tip of the cone.

The funnel shape of the cone allows for some misalignment during coupling. A similar cone shape connector was successfully used on Jeep Train II. The outside diameter of the cone is 20 inches based on the extremely severe static loading conditions shown in Appendix A. Dynamic loads will be limited, to correspond to these loadings, by use of proper hydraulic relief values. Should it be found desirable to use the coupling concept for water operation only; this diameter can be reduced to 14 inches.

5.2 CONTROLS

5.2.1 Background Experience

Contemporary articulated vehicles are all powered by a single engine and transmission located in one of the units (Ref. 1). Generally the engine is located in the same unit as the driver, thus, no special control is needed. Power is usually transmitted mechanically to the multiple elements via a mechanical drive line. Thus, the manipulation of engine and transmission controls is no different than in a single vehicle. Braking is usually done on the drive line. In the cases where the engine is in another unit, simple remote actuators are all that is needed.

However, in the case where individually powered vehicles are coupled together and their combined power output is utilized, it becomes necessary to perform all driver functions from one control station. Coupled rail-cars, powered trailers for heavy equipment, earthmovers, etc., are civilian examples of multi-engine applications.

The military experimented with multi-element vehicle trains in the 1960's, when several large ones were built using the locomotive concept with a single power source for the train. Another approach subsequently taken was to utilize individually powered units which could be used as a train or as single units. Stevens Institute investigated this concept by building two trains comprised of four jeeps, considered scaled models of larger units. The first jeep train was a proof-of-concept exploratory unit, (Ref. 2), the second a demonstrator of operational capability (Ref.3).

It was expected that the mobility of the train would exceed that of single units because of the assistance possible between units. But mathematical analysis and analog computer simulations showed that instabilities could arise from a mismatch of tractive effort in operations in difficult off-road terrain. Thus in the course of the design of the first jeep train, an electro-mechanical engine control system was designed which would allow the exploration of several modes.

The train was equipped with torque converter-automatic transmissions and an electro-mechanical engine control system which permitted the testing with simple throttle position control, engine speed control, drawbar force control or force and position modulated engine control. All brakes were centrally controlled and actuated by air. The train was fully instrumented to permit its evaluation in comparison to the analysis.

In over 300 tests involving all types of terrain and operational situations it was conclusively proven that none of the highly sophisticated control systems alleviated all of the less desirable tendencies of the train, and that driver reactions and reliability favored the simple throttle position control.

A second generation four-unit train using a simple master-slave pneumatic throttle control system was subsequently built as a demonstrator of operational capability. Any one unit could be a lead unit, only one driver was required. Each vehicle was equipped with a simple pneumatic throttle actuator, a torque converter-automatic transmission and pneumatically actuated brakes. The engine load was synchronized by adjusting all actuators to the same engine rpm at full throttle against the load of the torque converter at stall. Transmission range to be used was manually selected before getting underway. This train proved in many demonstrations that the simple master/slave system was successful in synchronizing the output from all four vehicles in all types, on-and off-road operation, ranging from extremely slippery terrain to severe hill climbing and (relatively) high speeds on roads. By being simple the system also proved to be very reliable.

The experience gained with the controls of the Jeep Train was then applied to the CCRV (Ref. 4). This vehicle consists of two standard M-113-A1 APC's coupled by a powered pitch and yaw controlled articulation joint. The purpose was to investigate the increase possible in mobility and obstacle crossing including the use of force feedback from the joint to the driver. Each engine was equipped to be remotely actuated by an electro-mechanical positional servo, actuating the governor controlled fuel injection pump. The master unit used its mechanical linkage for actuation. Its position was signaled to the slave which followed to the same position. The transmission selector was actuated using the same principle: the master retained its mechanical linkage; the slave followed by servo. Both controls were fail-safe so that the engine returned to idle and the transmission to low-low in case of electrical failure. The engines were started individually but could be stopped remotely. Again, in case of control failure, the slave engine would shut down. Signals for low oil pressure, no charge, and high temperature in the remote engine were transmitted to the master control station. The driver station could be switched from the first to the second unit, hence the need for remote actuators in each unit.

Deceleration was accomplished by downshifting while underway, and final stopping by using the brakes of the master unit only. This arrangement, although normally satisfactory, proved to be insufficient to come to a full stop on very steep downgrades.

Engine load was synchronized by matching engine rpm, at each position, against the stalled torque converter load. The transmission selector was matched to each of the positions. The coupling system was actuated by hydraulic cylinders and controlled electronically, which permitted several variations in control strategy, and positional and force feedback.

Control of the articulation motion was done by a simple joy stick; fore and aft movement provided pitch down and pitch up motion respectively; side movement produced the appropriate steering motion. Diagonal motions resulted in any combined pitch and yaw movement possible within the constraints of joint geometry. This system used positional control; that is, the vehicle attitude was proportional to the position of the control stick (such as in the steering of a car), in contrast to standard hydraulic systems which are flow controlled, such that the motion continues as long as the signal exists. The positional system proves to be highly successful and very natural to operate.

One of the main objectives of this venture was the investigation of the benefits of a force feedback system in which a proportion of the intervehicle pitching force was transmitted to the control stick. This feature provided the driver with a feel of the progress of the vehicle over an obstacle and was to compensate for the lack of visibility. Driver reaction to this feature was mixed and its merits were never clearly established. General-cross country operation was judged to be just as easy to handle without the force feedback system.

In as much as the coupled vehicles under consideration here can be considered a direct descendant of the CCRV, it is natural that its controls should be based directly on the earlier experience. Notable exceptions, in the interest of simplicity and reliability, will be:

1. Intervehicle force feedback to the driver will not be used
2. Transmission range selection can be done manually by the co-driver (in the other vehicle)
3. Vehicle braking to a stand still will be done with the help of the co-driver.

4. Engine start-up and shut down, as well as engine monitoring and other auxiliary functions, can be performed by the co-driver.

It is therefore recommended that the following controls be considered as the case may apply to either the coupled or articulated vehicle system.

5.2.2. Engine Control

Coupled Vehicles

In any set of two vehicles coupled together, one will be master and the other the slave. The driver is located in the master unit; the extra driver in the slave unit. It is imperative for proper operation of the coupled vehicles that both engines be operated in concert, and synchronized. The engine control of the master unit will be actuated with the standard mechanical linkage. A position pick-up (such as a potentiometer) transmits that position to a servo-actuator on the slave unit. This actuation will position the slaved control until the error signal is removed, i.e., its position is identical to that of the master unit.

The polarity of the system has to be such that the rack position goes to idle if there is a failure in the signal line. In the absence of an electrical signal, the engine of the slave vehicle is controlled by its mechanical linkage, just as during operation as a single unit.

Articulated Vehicles

There will be only one main engine which will be controlled either directly, or remotely, by the driver. The auxiliary engine is envisioned for emergency propulsion only, not in conjunction with the main engine, therefore there is no need for a master/slave arrangement.

5.2.3 Transmission Range Selection

Since there is to be a driver in the slave vehicle, remote transmission controls are not warranted. Transmission range can be selected manually on voice command. The articulated vehicle has only one transmission.

5.2.4 Brakes

Because it is anticipated that the vehicle will be coupled only under difficult off-road conditions where the rolling resistance is high, the braking of the combination is done within the transmission, resorting to power down shifting if necessary. The braking to a standstill can be done by voice command to the co-driver.

5.2.5 Steering in Pitch and Yaw

Coupled Vehicles:

The controls for steering and pitch actuation must be placed with the driver in the master unit. The joy-stick control of CCRV was highly successful; it was the best approach for a vehicle equipped with brake laterals. However, for vehicles equipped with a steering wheel, the yaw control may be incorporated into the natural steering motion via an electrical command signal. Depending on the steering characteristics of the transmission it may be necessary to coordinate the joint steering command with that of the transmission. The joint will be actuated hydraulically, pitch and yaw may be interrelated or separate depending on design. The control signal will be electrical, controlling either flow control valves or pump stroke. The pitch command can be built into a fore-and-aft motion of the steering column or tilt motion of the wheel (which can be locked out for single operation). All controls will have positional feedback.

Articulated Vehicles

Steering and pitch control can be by either steering wheel or joy-stick linked to the hydraulics actuating the joint. In normal operation there is no need for interaction with the transmission because of the use of open differentials. Under emergency conditions, when the forward unit is jettisoned, the articulation joint hydraulics will supply power to two hydraulic motors in the final drive of the rear unit, using the same controls. If the driver is located in the rear unit, the main engine and transmission have to be controlled remotely but the articulation controls are directly connected to the hydraulics. If the driver is in the forward unit the above is reversed, and a co-driver is needed in the rear for emergency operation. All articulation joint controls will have positional feedback.

5.2.6 Coupling Connect and Disconnect

Routine coupling and uncoupling applies only to the coupled vehicle concept. Connecting the coupling on land or in water has to be done by the driver in the rear unit; only he has the proper visibility to perform this function. Communication during this phase has to be by radio link since the hardwire connection does not exist until the vehicles are linked up. Differences in elevation of the two mating parts have to be adjusted by joint motion. Lateral misalignment can be compensated for by steering the single (trailing) vehicle and by the yaw articulation. This type of linking up has been done successfully with the CCRV. Coupling under extreme attitudes, such as one vehicle stuck in a ditch, may well not be possible.

Uncoupling of the vehicles will be possible at the option of each driver and probably at just about any attitude. The engine control will return to the mechanical mode and to the fail-save position because the command signal is lost, alerting the co-driver that he is back in control. The pitch and yaw actuation becomes inoperative because the vehicles are disconnected. All other functions, having been performed by each driver while coupled, remain the same when single.

The articulated vehicle is not intended to be easily, or routinely coupled and uncoupled in the field. There will be a provision to forcibly separate the units, in an emergency such as by detonating links; once that has been done the re-joining of sections is not expected to be a field operation.

5.2.7 Water Steering

The CCRV, being assembled of two M-113's which have track propulsion only, showed that the coupled units being steered by yaw articulation only had the same maneuverability as a single unit steered with differential track speed.

In the case of an amphibious vehicle with separate water propulsion devices it is expected to be of advantage to steer with both yaw articulation and the propulsors. For vehicles with a cross-drive transmission, this will not require special controls since the yaw articulation has to be connected into the normal steering mode, and the land and water mode steering system are interconnected for singles operation. Coordinating the propulsors with articulation will also prevent interference of the propulsor stream with the stern section.

5.2.8 Miscellaneous

Coupled Vehicles

Since there is a co-driver in the slave unit, a number of functions not critical in their exact timing can be performed by the co-driver in communication with his master. In this category are:

1. Engine starting and stopping
2. Transmission range shifting
3. Brake application to augment transmission retardation
4. Engage water propulsion
5. Observation of low oil pressure, high temperature, low voltage, etc.
6. Activate bilge pumps
7. Uncoupling or coupling
8. Overriding any automatic function when necessary.

Articulated Vehicles

If the driver is placed in the forward section, then the co-driver in the troop section is responsible for the monitoring of the auxiliary engine and the functions it performs. He also communicates to the driver any observations which might affect the operation of the articulated vehicle and which cannot be displayed to the driver.

6. PERFORMANCE EVALUATION

6.1 LAND PERFORMANCE

6.1.1 Tractive Effort

For a track-laying vehicle, the tractive effort versus speed characteristic presents the maximum force available at the sprocket from the powertrain (engine/transmission) at a given speed. If two identical vehicles are coupled, each can produce the same sprocket torque at a given speed so the shape of the tractive effort versus speed curve is the same for a single vehicle or the combination, but the coupled pair has double the tractive effort available (as well as double the weight of a single unit) (Reference 5).

For the articulated concept, as discussed earlier, a new powertrain was laid out (Figure 15). The tractive effort versus speed graph (Figure 18) for the engine and transmission selected suggests that the manual transmission chosen for simplicity is not the optimal choice in this case. In particular, the addition of a torque converter would increase the tractive force available at low speeds.

6.1.2 Acceleration

The ability of a vehicle to reach a certain speed and to cover a certain distance as a function of elapsed time from a standing start is simulated in the acceleration analysis. The acceleration graphs present these results for various surfaces. For this analysis, the rolling resistance (soil motion resistance plus suspension rolling resistance) is assumed to be a fixed percentage of gross vehicle weight. The possible difference in soil motion resistance between a single vehicle and a coupled pair of vehicles, discussed below under soft soil, was not considered here.

Because of the assumption that the ratio of motion resistance to weight and therefore that of tractive effort to weight, is the same for the single and coupled vehicles, there is no difference in the acceleration of the single and the coupled vehicles with full power. However, the coupled vehicles provide the possibility of operation with reduced performance even if one of the units is totally without power. To assess this capability, the acceleration simulation was run for the coupled vehicles with both vehicles powered and with only one vehicle of the combination powered. This simulation was done with five values of the ratio of motion resistance to vehicle weight and for three vehicles, the LVTP-7, the M113-A1 and a paper concept. The three vehicles vary in weight from 22,600 to 52,000 pounds per unit and the concept has a higher power to weight ratio. The results are presented in Appendix B. Figures 19 and 20 show, as an example, the comparative performance of coupled P-7's with either one or two engines operational. In all cases, the performance remaining to the coupled vehicle with one unit disabled is felt to offer a useful operational capability.

In order to obtain comparable results for the articulated concept further operational options have to be established: In normal operation, tractive power is provided by the main engine in the front unit. For the disabled unit performance simulation, it is postulated that: 1) the main engine is disabled, and that all power is provided by the 100 HP engine normally used for auxiliary power; and 2) that the forward unit has been jettisoned and the rear unit only is propelled by the auxiliary engine. It is further assumed that 20% of this power will still be needed for other purposes and that the emergency powertrain has 80% efficiency. The simulation was run only at a single value of 90 lb/ton motion resistance since the prior analysis for the coupled vehicles had shown no qualitative differences in the trend with change in this parameter. The simulation was performed both with the two-section articulated vehicle powered by the auxiliary engine and then with only the rear (personnel) section so powered. The results are presented in Figures 21 and 22. The degradation in performance is, of course, considerable but the remaining operational capacity is still significant in terms of the vehicles' survival.

6.1.3 Soft Soil Performance

Two soil measurement systems are presently in use to assess vehicle performance in soft soil. One is the Cone Index system, and the other the Bekker system. Both have been developed primarily for standard (single unit) tracked vehicles.

To use the Cone Index system, the vehicle cone index (VCI_1) is first calculated for each vehicle. VCI_1 represents the minimum soil strength (in rating cone index) required for the vehicle to make one pass through the soil, i.e., if the soil strength (RCI) in a region does not exceed VCI_1, the vehicle cannot operate in the region. VCI_1 which is primarily a function of average ground contact pressure, provides a general measure of gross vehicle mobility. In addition, knowing the VCI_1, and the soil strength and type in a region, one can calculate the rolling resistance expected in the first pass through the region.

In the case of the coupled vehicles, this approach must be taken cautiously. If the coupled vehicle is merely regarded as a larger and heavier tracked vehicle, a single unit and a coupled pair of identical units have the same VCI_1. Then for any soil, the cone index system calculation will yield the same resistance to vehicle weight ratio. However, the real situation is better viewed as identical vehicles making a first and second pass through the soil. One should calculate VCI_2 (second pass vehicle cone index) for the second vehicle and a corresponding resistance. The published data which is the basis for the cone index relationships is primarily the result of first pass tests. There have been some tests performed to assess capability to traverse a region 50 times which have resulted in the equation for VCI_{50}, the 50-pass vehicle cone index (i.e., the soil strength required to permit a vehicle to pass over the soil 50 times) but VCI_2 has not been considered. VCI_1 and VCI_{50} are listed in Table III for the single and coupled M113 and LVTP-7 and for the articulated concept. All were calculated as if the multi-unit vehicles are long single-unit vehicles.

In an attempt to obtain some quantification of the difference in soil motion resistance between a single and coupled vehicle, the Bekker soil system was used to calculate the sinkage and total soil motion resistance in selected critical soft soils. As the Bekker methodology accounts for the difference in compaction from the first and the later road wheels, the resulting resistances reflect the fact that the second unit rides in the rut from the first unit. On the selected soils, decreases in resistance to weight ratio of 10 - 20 % were predicted for the coupled vehicles over the resistance ratios for a single vehicle. The results are presented in Table IV. This agrees with the Drawbar Pull Tests of the CCRV (Reference 5).

6.1.4 Obstacle Negotiation

In many terrains, the major impediment to vehicle travel comes from the obstacles (natural or man-made) which must be negotiated or avoided. Since going around impassable obstacles causes an increase in travel time, improvement in capability to negotiate obstacles can yield a significant increase in overall mobility.

Coupling vehicles is a way to obtain improved performance, in this respect, for several reasons. The first can be regarded as a scale effect. The coupled vehicle is, in effect, a larger vehicle and in general, the larger the vehicle is the larger the obstacle must be to stop it. The second reason for improvement in performance comes from the greater ability of the coupled (or articulated) vehicle to conform to the surface and utilize its full tractive power. A third reason is that the intervehicle forces that are exerted will compensate for those that cannot be generated by tractive effort on the obstacle. We will now briefly examine and quantify this performance improvement in three situations.

6.1.4.1 Step Climbing

When a tracked vehicle confronts a hard vertical step (wall) on a hard surface, the limiting factor is the height at which geometric interference prevents the track from contacting the step. Field trials indicate that when the track can engage the step, vehicles of the type considered here, have sufficient power to climb the step.

The LVTP-7 is specified to handle steps up to 3 feet high. The M-113 will climb a 2 ft step. Powered articulation provides a way to raise the front of the coupled vehicle so that the track will reach a higher point on a step. The height reached is a function of the location of the pitch pivot, the degree of pitch possible and the suspension spring constants. Field tests of the CCRV (coupled M-113's) demonstrated that a 5 ft high wall was negotiable as shown in Figure 23. Using the CCRV as a scale model, the larger LVTP-7, calculated to attain the same pitch attitude, can be expected to climb a 7 ft high wall as shown and compared to a single P-7 in Figure 24.

6.1.4.2 Trench Crossing

The ability to cross a hard surfaced trench is also essentially a geometric problem. The limiting dimension is approximately the smaller of the horizontal distances from the center of gravity to the first and last road wheel centerlines. The vehicle can bridge any gap smaller than this value (which is at best half the track length). If the gap is larger, the vehicle will fall into the gap and encounter interference. (There is a small safety margin by contacting with the portion of the track between the limiting roadwheel and the sprocket or idler.) For the coupled vehicle, the combined center of gravity is between the tracks of the front and rear unit, thus the vehicles can bridge a gap as wide as the length of contact of one of the tracks. Hence, the coupled vehicle can cross gaps at least double the width of those which the single vehicle can bridge, as shown in Figure 25.

Again by using the CCRV as a scale model, its demonstrated capability to cross an 11 ft wide trench is used to project a conservative 14 ft (possibly 16 ft) width for the coupled P-7 in Figure 26, compared to the 8 ft capability of a single P-7 in Figure 27.

6.1.4.3 Climbing of Natural Terrain Feature Obstacles

A finely detailed analysis of the motions of and forces on a vehicle during negotiation of a general obstacle (i.e., an obstacle having an arbitrary shape and soil) would require extension of existing methodology. The most recently developed simulation obstacle negotiation is that called OBS78B, which is a part of the NATO Reference Mobility Model, Edition I completed in the Spring of 1979 (Reference 6). In this simulation, all compliance and dynamic effects are neglected, the obstacles are symmetric trapezoids and motion resistance is accounted for through a uniform coefficient. The simulation only deals with single unit tracked vehicles and even these are modeled as equivalent wheeled vehicles. A validation program and further development of this simulation are planned. An extension to articulated tracked vehicles is highly desirable, but some distance in the future.

Consequently, for this study, a "quick look" approach was taken for this obstacle negotiation problem. In the LVA Concept Analysis (Reference 7), the Linear Features/Obstacle Module was designed to assess the vehicle's capability at those points in the obstacle negotiation which were judged to be the critical places. Mission scenarios typical of operational conditions which would be encountered by this class of vehicle were defined.

Reviewing the results of the LVA Mobility Analysis it was observed that all of the NO-GO's identified for the LVTP-7 had the same cause. This was a lack of sufficient tractive force to climb the obstacle due to a combination of weak soil and obstacle geometry (approach slope and obstacle height).

The advantage of coupled vehicles lies in the capability of the unit which is still (or, again) on level ground to assist the unit on the slope. If the slope is long enough for both vehicles to be on it at the same time, there is no benefit to coupling.

The basic relationships for this analysis are presented in Appendix C. The results of the analysis comparing single and coupled units of P-7 size on an obstacle of a height arbitrarily chosen as 200 inches are given below:

SOIL TYPE		Limiting Slope (Degrees)	
		Single	Coupled
Cohesive	c = 3 psi	14.0	28.5
	c = 4 psi	23.5	46.5
Frictional	$\varphi = 20^o$	15.5	31.0
	$\varphi = 25^o$	21.5	45.0

6.1.5 Water Exiting

At the present time there is no acceptable analytical procedure available to calculate the exiting capability of vehicles, let alone coupled or articulated ones. Therefore, the same procedure was used as for the obstacles, that is, to compare the coupled vehicles to the known performance of the CCRV of Reference 5. For that purpose, the floating trim attitude of the coupled P-7 models was measured in the towing tank, and found to be identical to that of the CCRV. Figure 28 shows the two vehicles in their static floating attitude against a 34^o shore slope which the CCRV was able to negotiate. In Figure 29 it is clearly evident that the trimmed up P-7 has the advantage of engaging the shore slope with the front approach slope of the track, whereas, the single vehicle engages the shore with the bow section of the hull. It is reasonable to assume that the performance of the coupled vehicle will match that of the CCRV whose exiting performance is known in Figure 30, as reproduced from Reference 5.

6.1.6 Corridor Turning

A computer simulation has been developed by Stevens Institute of Technology (Reference 8) to evaluate the corridor turning performance of a vehicle. Both conventional tracked vehicles and vehicles steered by articulating can be analyzed. The program simulates a vehicle turning in an L-Shape (perpendicular) corridor.

Figure 31 is a representation of a conventional tracked vehicle of length l, and width w, traversing an L-shaped corridor having street widths of a and b. The vehicle clearance and minimum clearance radii as well as the path radius of the vehicle center of gravity are calculated using the geometric fit of the rectangular shape through the corridor. Figure 32 shows the results for a single P-7.

The evaluation of a vehicle steered by articulation is similar to that for the single vehicle. It is based on the geometric relation of moving a single box shape as shown by the dotted lines superimposed in Figure 33 through the corridor. The input parameters are the length of the coupled vehicles, the vehicle width, and the maximum allowable articulation angle.

An additional constraint is imposed by the geometry of steering by articulation. Accordingly, the method for calculating the vehicle clearance radius, the minimum clearance radius and the corridor width as a function of yaw angle, and vehicle length and width is shown in Figure 34. It assumes identical box-like vehicles and a symmetrical relationship.

Some representative comparison values are:

	P-7	Coupled P-7
• Vehicle clearance radius	16.5 ft	61 ft
• Minimum corridor width required	16.5 ft	27.5 ft

The limitations on vehicle turning imposed by the transmission are considered next. Figure 35 shows the relationship between vehicle speed and path radius for the LVTP-7 with the HS-400 transmission. Note that while the vehicle can make a pivot turn, it does such a turn in neutral at zero speed.

Figure 36 shows a combination of the transmission capabilities and the vehicle geometry limitations, defining the areas of useful operation of the single and the coupled P-7's.

6.1.7 Cross Country Ride

Cross country vehicle performance is limited by a variety of factors. In soft soil, lack of power or the ability to transmit the power to the soil may be the limiting factor. In other places lack of visibility or maneuvering around and among obstacles and vegetation can be the primary factor. On relatively hard surfaces, the limiting factor is often the driver's tolerance to his vibrational environment when the vehicle is operating over continuously rough ground and/or the driver's tolerance to impacts received while the vehicle is crossing discrete obstacles. The vehicle/driver/terrain interaction, together with the related vibrations and impacts at other locations in the vehicle, are usually referred to as "ride".

Articulation and coupling has long been recognized as a way to obtain a significantly better ride in tracked Vehicles (Ref. 1). This is due to the articulated vehicle having greater length than a comparable single vehicle as well as power absorption in the coupling. This was also borne out by the ride evaluation test in the CCRV program, which was conducted over a single course having an RMS roughness of about 2 inches. Compared at the commonly used power absorption level of 6 watts in the vertical direction at the drivers' seat, the coupled units could be driven 50 percent faster than the single unit in rigid mode (length effect) and twice as fast in a limited pitch freedom mode (combined length and damping effects) (see Figure 37, borrowed from Reference 5).

Computer programs to predict ride quality exist. They are time consuming and costly to run. The accuracy of the output is dependent on the accuracy of input parameters whose values are usually difficult to obtain. For these reasons, a complete ride analysis was judged to be beyond the scope of this study.

6.1.8 Land Performance Summary

A summary comparing the known land performance of several existing vehicles with the projected performance of the concepts is presented in Table V.

6.2 WATER PERFORMANCE

The behavior of the coupled LVT in calm water and head seas was determined from sub-scale model tests using 1/8.2-scale models. This section describes the models used, the test techniques, the results obtained and discusses the full-scale predicted performance.

In order to give the model study a degree of realism, the tests were based on the LVTP-7 amphibious tracked vehicle used by the Marine Corps. It should be recognized that the characteristic behaviour of the coupled LVT is not dependent on the specific vehicle type and as far as possible the results and conclusions are presented in a form independent of the specific configuration. The selection of the P-7 for the purpose of making model tests was discussed with and agreed to by DTNSRDC Code 112.

6.2.1 Model Description

Two models of the LVTP-7 were built and one of the pair is shown in Figure 38. Each model had an overall length of 38 inches (a model scale of 1/8.2) and was built to FMC Dwg. No. 4168484. The pine models incorporated flexible tracks, moveable suspension systems and individual road wheels which could be adjusted to allow for track extension.

The models were coupled together with a spacing between them corresponding to 14 inches: hereafter all quantities will be given in terms of full-size equivalents. The coupled models could be run free-to-pitch about the main bearing located 56 inches above the vehicle base line and midway between the two vehicles. The relative incidence between the coupled vehicles would be fixed by means of a pair of adjustable tie rods between the lead and trailing vehicle located 8.75 ft. above the base line and spaced 5 ft. apart to allow for yaw adjustment.

The lead model was equipped with a free-to-trim towing fitting whose pitch axis was 170 inches aft of the bow and 51.7 inches above the base line (STA 204 and WL 51.7). Both models had accelerometers located at STA 178 on the model centerline to measure the vehicle acceleration in the rough water tests. In order to measure the bending moment between the coupled vehicles in waves, the adjustable coupling was replaced by a strain-gaged beam for a limited series of tests.

Model particulars are given in Table VI.

6.2.2 Test Program

Tests were conducted in the Davidson Laboratory Tank 3 test facility, a high speed towing tank 300 ft. in length, 12 ft. wide by 6 ft. deep, equipped with a monorail drive and plunger wave maker.

The test models were ballasted to draft marks corresponding to the Combat Equipped LVTP-7. This loading was selected as being the most severe because the associated forward LCG on the current LVTP-7 A1 leads to green water over the bow at intermediate speeds. Tests were also run at the Combat Loaded Condition:

Condition	Weight, lb.	*LCG,STA	LCG,%L
Combat Equipped	42,377	187.89	49.3
Combat Loaded	52,377	199.85	53.2

*Longitudinal locations on the P-7 are conventionally given in terms of Stations which are distances aft of the bow in inches plus 34 inches. Positions as a percentage of the overall length are obtained by subtracting 34 and dividing by the length of 312 inches.

Tests were run with the single vehicle in calm water over the speed range of 4 to 9 mph in order to provide correlation between model and full-scale data. In this as in all the tests, the tracks were extended and hung in a free catenary taken to be representative of operating conditions.

The models were then coupled together and a series of calm water exploratory tests were run to determine the effects of relative incidence between the models, locked versus free-to-pitch coupling, and spacing. The test conditions were selected from the following matrix:

Load Condition	Combat Equipped
Speed, mph	4,5,6,7,8,9,10,11,12,13
Relative Incidence, Deg.	Free, 0,2.7,4,5.5,7,10,15
Inter-Vehicle Spacing, In.	14, 30

Head sea tests in Sea State 2 (significant wave height 2.2 ft.) were then run for the following conditions based on the findings of the calm water exploratory tests:

Load Condition	Combat Equipped
Speed, mph	6 and 8
Relative Incidence, Deg.	Free, 0, 10, 15
Inter-Vehicle Spacing, In.	14

On the basis of deck wetting and driver visibility the 15 degree incidence was selected as optimum: in the static condition at this relative incidence the coupled vehicles floated with the lead vehicle at a bow-up trim of 7 degrees and the trailing vehicle in a bow-down attitdue of 8 degrees, Figure 39. The drag of the coupled vehicles did not vary with incidence and changes in vehicle spacing had no significant effect.

With the coupled vehicles at 15 degrees incidence and 14 inches spacing the following conditions were run in calm water and head seas:

Loading, lb.	42,377 and 52,377
Speed, mph	4, 5, 6, 7, 8, 9, 10, 11, 12, 13
Significant Wave Height, Ft.	2.2 and 3.3

In addition, the effect of fitting a bow extension to the lead vehicle was investigated. Both buoyant and non-buoyant extensions (5 ft. by 5 ft. in planform) were tried.

6.2.3 Test Results

The measured quantities included the drag, trim and draft of the lead vehicle in calm water. In the head sea tests these measurements were supplemented by recordings of the accelerations in the lead and trailing vehicles at points 46% of the vehicle length behind the bow of each vehicle.

The test results are discussed in the following sections and are presented graphically in Figures 40 through 51.

In addition to these quantitative results, video tape recordings were made of the rough water tests, the head and beam sea coupling experiments were recorded on motion picture film, and still photographs were taken of representative test conditions.

6.2.4 Full-Scale Predictions

6.2.4.1 Single Vehicle in Calm Water

The model results are expanded to full-scale by a technique known as Froude Scaling in which velocities are multiplied by 2.86 (the square-root of the 8.2 scale ratio) and forces are multiplied by the cube of the scale and by the ratio of the density of salt water to fresh water, which is the displacement ratio of 566. To demonstrate the validity of this technique the results are compared to the full-scale values obtained with the prototype LVTX-12 in Figure 40.

Although the LCG on the prototype LVTX-12 was 6.5 inches further aft than that of the LVTP-7, good agreement was obtained between the model and full-scale results (Reference 9).

Also shown on this plot is the thrust available from the jet assuming an installed power loading for the P-7 of 21 Hp/ton, an allowance for auxiliaries of 17.5% and an overall propulsive coefficient of 40% based on the trial results. It is clear that the P-7 has the power to go faster if it were not for the decrease in trim above 8 mph. The results of the prototype trials contain the observation that the speed is limited by the (negative) vehicle trim.

6.2.4.2 Coupled Vehicle in Calm Water

The calm water drag of the coupled vehicle at the combat equipped weight is shown in Figure 41 and contrasted with that of the single vehicle.

The relative incidence between the coupled vehicles has no effect on the drag, so that the incidence may be selected on the basis of running attitude and water shipped over the bow and on to the driver's station. Variation in spacing between the vehicles also had no effect on the drag so that this parameter may be selected to accommodate the yaw angle necessary to steer the vehicle. The drag of the coupled vehicle, on a per ton basis, is about 75% that of the single vehicle due to doubling the length; above 8 mph the coupled vehicle has a speed advantage of 2 mph for the same installed power, since it does not bury its bow like the single vehicle. Thrust available from power installations of 20 and 30 Hp/lb. are shown in Figure 41 to show the increasing speed advantage of the coupled vehicle as the power increases.

The increase in the running trim of the lead vehicle as the relative incidence is increased is shown in Figure 42. The nose-diving of the single vehicle above 8 mph is obvious in the trim track at the bottom of the figure. At 15 degrees incidence the bow-up trim of the coupled vehicle increases with speed with no tendency to bury the bow at intermediate speeds. Beyond 15 degrees incidence the vision blocks at the driver's station of the trailing vehicle would be continually under water. Therefore the 15 degree incidence was identified as an appropriate attitude in which to run the main investigation including the study of rough water behavior.

The drag of the combat loaded coupled LVT, at 15 degrees incidence, is 7% less than that of the combat equipped vehicle as shown in Figure 43. The trim of the heavier vehicle is also half a degree higher, and therefore the bow drier, than at the combat equipped load. Thus, the performance of the combat loaded coupled LVT is better than that of the combat equipped vehicle, since the drag in pounds per ton of the heavier vehicle is 7% less and the trim is half a degree higher. These considerations lead to the choice of the combat equipped vehicle as the configuration to be used in the preliminary coupling experiments.

The calm water tests showed that coupling two LVT together resulted in significant drag reduction, eliminated bow burying and thereby opened the way for speed improvements of 2 to 4 mph depending on the installed power. Speed improvements that could not be obtained with the basic P-7 no matter what the power because of water over the bow. These improvements in performance were obtained with a modest relative incidence of 15 degrees and only got better as the vehicle weight was increased from combat equipped to combat loaded.

6.2.4.3 Seakeeping of Coupled Vehicle

The performance of the coupled LVT in head seas of 2.2 ft. significant wave height (Sea State 2) is shown in Figure 44. For the coupled vehicle operation in this sea state reduces the maximum speed by only 0.5 mph. Compared with the single vehicle in the same sea state, however, the coupled vehicle can operate at 10 mph whereas the single vehicle is limited to speeds of about 6 mph. The reason for this is excessive water over the bow of the single vehicle at speeds above 6 mph. This situation is illustrated by Figure 45 where the single and coupled vehicles in Sea State 2, running at 6 and 10 mph respectively, are shown. It may be noted that to achieve a speed of 10 mph with the coupled LVT does not require a large power installation: in fact a power loading of 22.4 Hp/ton as in the current LVTP-7 would be sufficient. On the other hand, no amount of installed power will make the single vehicle go faster because of the diving tendency.

The seakeeping behavior of the coupled vehicle is summarized in Figure 46. The RMS vertical acceleration 9 inches ahead of the CG of the lead vehicle is shown in the upper graph as a function of speed. The acceleration at the corresponding point in the trailing vehicle is 40% less. The accelerations are quite modest and are seen to reach their maximum at 8 mph where for the combat equipped lead vehicle the RMS acceleration is 0.08g and the average of the 1/10 highest peak acceleration is 0.2g. Increasing the weight from combat equipped to combat loaded decreases the accelerations and the motions as shown in the lower plot. Increasing the speed from 6 to 10 mph reduces the pitching and heaving motions 30%. While the accelerations in the single and coupled vehicle are similar, the motions of the coupled vehicle are much smaller in the 4 to 6 mph speed range.

The ride quality in Sea State 2 at 8 mph in the combat equipped condition, where the coupled vehicle experiences the largest accelerations, is shown in Figure 47. The lead vehicle of the coupled LVT shows a peak RMS acceleration at 0.4 Hz that is 15% higher than the single vehicle; however, operation of the single vehicle at 8 mph is barely practical due to bow burying. Either configuration is well below the one hour exposure "fatigue decreased proficiency" limit recommended by the International Standards Organization, and both are below even the ISO two hour exposure limit.

The tests in waves showed that the coupled LVT behaved well at speeds up to 10 mph. Above this speed in headseas, however, considerable water was shipped over the bow. An experiment was conducted in which a 5 ft. bow extension was fitted as shown in Figure 48. The non-buoyant extension was very successful in suppressing the bow waves at speeds of 10 and 12 mph as shown in Figure 49. With sufficient power installed this simple bow extension, which could easily be folded when not in use, would extend rough water operation to at least 12 mph. The effect on the seakeeping performance is shown in Figure 50 for Sea States 2 and 3 (significant wave heights of 2.2 and 3.3 ft.). The increase in drag between Sea States 2 and 3 is minor and while the acceleration in Sea State 3 is 50% greater than in Sea State 2, the 1/10th highest acceleration in Sea State 3 is still only 0.3g.

The possibility of coupling the two vehicles in a seaway was examined in a qualitative manner. The uncoupled vehicles were placed bow-to-stern in head seas and beam seas and their resulting motion recorded on color motion picture film. Targets and grids were mounted on the models to assist in estimating the resulting motions. It seems unlikely that the vehicles could be coupled in head seas due to the excessive relative motions. Coupling in beam seas might be possible and deserves further study if an operational need develops.

In order to determine the bending moment between the vehicles, and consequently the size of the coupling, the rigid coupling was replaced by a strain-gage beam that held the models at a relative incidence of 15 degrees. The models were run in head seas of State 2 up to 12 mph and time histories of the bending moment were recorded and analyzed. The mean bending moment is shown in Figure 51 together with the maximum and minimum values. This data was used to size a "water-only" coupling.

6.2.5 Hydrodynamic Performance Summary

A summary of the hydrodynamic performance is presented in Table VII.

ACKNOWLEDGEMENTS

This study was conducted under the sponsorship of the Department of the Navy, for David Taylor Naval Ship Research and Development Center, Code 112. The authors acknowledge the direction and useful guidance received during this project from Messrs. Ed O'Neill and Ernest Wolfe of the Systems Development Department.

Very appropriately, for an amphibious vehicle investigation, this effort integrated the capabilities of the Transportation Research Group for the land mobility studies, and the Marine Development Group for the hydro-dynamic evaluation, combining the talents of staff members with many years of experience in the several fields involved.

Jan Nazalewicz generated many of the concept designs and performed the structural analysis. Aldo Sori produced understandable and presentable figures from "back-of-the-envelope" sketches. David Sloss organized much of the land performance evaluation. Dennis Calbeck devised the corridor turning analysis. Gerald Fridsma and Walter Klosinski conducted the hydro-dynamic test program. Dr. Robert Ehrlich made his extensive vehicle and mobility experience available in the many review and critique sessions. Mary Ann McGuire and Anita Giaimo patiently typed the report. Dr. Daniel Savitsky provided overall management for the project.

Last, but not least, the authors wish to acknowledge that this study would not have occurred without the pioneering efforts in the development of articulated tracked vehicles of Clifford J. Nuttall, now at the U. S. Army Engineers Waterways Experiment Station. Much of this work is contained in the basis for this study and the authors have benefitted from his advice during the conduct of this project.

Our thanks to all.

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TABLE I. PAST ARTICULATED VEHICLES

An Overview

		DIPLOCK	RAT XM 571	POLE CAT	MUSK OX	COBRA	NODWELL	XM 561 GAMA GOAT	GOER	8 x 8 TWISTER	BV 202	COUPLED M113 s	BV 206	XM 808 6 x 6 TWISTER
WHEELED/TRACKED		TR	TR	TR	TR	TR	TR	WH	WH	WH	TR	TR	TR	WH
YEAR		1912	1955 1963	1957	1959	1953	1953	1965	1962	1965	1963	1975	1979	1970
YAW	POWERED	Steered	X	X	X	X	Steered		X	Steered	X	±31°	X	
	FREE							X					--	FIXED
PITCH	POWERED					X				--		+20° -28°	STEER A MODEL	
	FREE	±5°	X	X	SHOCK ABSORBER		±10°	±40°	+20° -28°	+35° -27°	SHOCK ABSORBER			
	RIGID								X	X				x
ROLL	FREE	±5°	X	X	X	X	X	X		X	X	X	X	±25°
	RIGID						LIM	±15°	X	±30°	40°		LIM	
TRANSMIT POWER		YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	NO	YES	YES
CAN SUPPORT REAR UNIT		NO	NO	YES	NO	YES	NO	NA	NO	YES	NO	YES	?	?
REMOTE COUPLING		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
BRIDGING CAPABILITY		NO	NO	NO	NO	YES	YES	NO	NA	YES	NO	YES	NO	YES
SINGLE UNIT OPERATIONS		NO	FRONT ONLY	NO	NO	NO	NO	FRONT ONLY	NO	NO	NO	BOTH	NO	NO

TABLE II. PRIMARY EVALUATION FACTORS

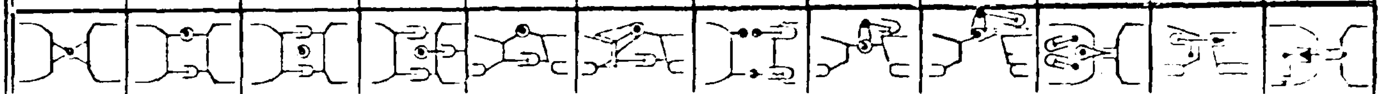
PRIMARY EVALUATION FACTOR \ CONCEPT	1	2	3	4	5	6	7	8	9	10	11	12
												
RANGE OF MOTION Yaw Pitch Roll	LIMITED FREE LIMITED	POWERED FREE LIMITED	POWERED FREE LIMITED	POWERED POWERED LIMITED	POWERED POWERED LIMITED	POWERED POWERED LIMITED	POWERED POWERED FIXED	LIMITED POWERED LIMITED	POWERED POWERED FREE	POWERED POWERED FREE	POWERED POWERED FREE	POWERED POWERED FREE
POWER SUPPLY FROM Front Unit Rear Unit Type (Hydro, Mech., Elec.)	NONE	FRONT HYDRAULIC	FRONT HYDRAULIC	FRONT HYDRAULIC	FRONT HYDRAULIC	FRONT HYDRAULIC	FRONT HYDRAULIC	FRONT HYDRAULIC	FRONT YAW-HYDR. OR EL. PITCH-HYDR.	REAR HYDRAULIC	REAR HYDRAULIC	FRONT & REAR HYDRAULIC
CONTROL FROM Front Unit Rear Unit Type	NONE	FRONT MECH. HYDRAULIC	FRONT MECH. OR ELECTRO- HYDRAULIC	FRONT MECH. OR ELECTRO- HYDRAULIC	FRONT MECH. OR ELECTRO- HYDRAULIC	FRONT MECH. OR ELECTRO- HYDRAULIC	FRONT MECH. HYDR.	FRONT MECH. HYDR.	FRONT YAW ELEC. MECH. HYDR.	FRONT ELECTRIC REAR EL./HYDR.	FRONT ELECTRIC REAR EL./HYDR.	FRONT REAR MECH. ELECTRIC HYDRAULIC
REMOTE COUPLING	LIMITED	NO	NO	NO	NO	YES	POSSIBLE	YES	YES	YES	YES	YES
REMOTE UNCOUPLING	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
INTERFERENCE WITH Stern Ramp Troop Exits Cargo Hatches Angle of Approach/Departure Pivot Turn Clearance Water Jets Armament	NONE	STERN RAMP INCREASED PIVOT TURN CLEARANCE	PIVOT TURN CLEARANCE	CARGO HATCH PIVOT TURN CLEARANCE ARMAMENT	PIVOT TURN CLEARANCE	STERN RAMP DEP. ANGLE WATER JET PIVOT TURN CLEARANCE	PIVOT TURN CLEARANCE	CARGO HATCH ARMAMENT PIVOT TURN CLEARANCE	CARGO HATCH ARMAMENT PIVOT TURN CLEARANCE	PIVOT TURN CLEARANCE (SLIGHT)	STERN RAMP PIVOT TURN CLEARANCE	STERN RAMP PIVOT TURN CLEARANCE
SPECIAL STRUCTURE REQUIRED Bow Stern Sides Top Articulation Stops	BOW	BOW STERN SPECIAL STOPS	BOW ROLL STOPS	TOP BOW STERN	TOP STERN	BOW STERN- SIDE	BOW STERN	TOP BOW	TOP BOW	BOW INTERNAL	BOW INTERNAL STERN	BOW INTERNAL STERN
GRAVITATION COMPONENT FAVORS Front Unit Rear Unit	NA	NA	NA	FRONT	50/50	50/50	NA	FRONT	50/50 YAW STEER UNSYMMETRIC	REAR	50/50	FRONT
FORCE LIMITATION Yaw Pitch	NA NA	NO NA	NO NA	NO NO	INTER RELATED	INTER RELATED	ROLL	NA	NO	SPACE LIMIT	SPACE LIMIT	SPACE LIMIT
CHANGE IN WEIGHT OF INDIVIDUAL VEHICLE Distribution, Front/Rear	50/50	40/60	60/40	55/45	45/55	35/65	45/55	40/60	30/70	65/35	65/35	50/50
VULNERABILITY PROTECTABILITY	GOOD	POOR	POOR	POOR	POOR	POOR	POOR	POOR	POOR	GOOD	GOOD	GOOD

TABLE III. SOFT SOIL VEHICLE PERFORMANCE COMPARISON

Critical Fine Grain Soils

Cone Index Method

DATA	VARIABLE	LVTP-7	M113-A1	LVTP-77*	M226**
Gross Vehicle Weight	GVW	51,984	22,600	103,968	45,200
Track Length	TL	152	105	304	210
Track Width	TW	21	15	21	15
Grouser Height	GW	2	2	2	2
Track Shoe Area	AT	126	90	126	90
No. of Road Wheels	NBC	12	10	24	20
Horse Power/Ton	HPT	15.4	18.5	15.4	18.5
Ground Clearance	XC	16	16	16	16
VCI_1 (One Pass - Straight)		15	15	15	15
VCI_T (One Pass - With Turn)		19	19	17	17
VCI_{50} (50 Pass - Straight)		36	36	36	36

CI	SCENARIO I FINE GRAIN SEGMENTS	TOTAL MOTION RESISTANCE: POUNDS/TON			
		LVTP-7	M113-A1	LVTP-77*	M226**
20	38, 73, 107	491	491	491	491
25	None	370	370	370	370
29	34, 36, 40, 42, 44, 106	315	315	315	315
30	None	305	305	305	305
35	None	264	264	264	264
36	32, 46, 50, 87	258	258	258	258
40	None	237	237	237	237
50	30, 48, 52, 54, 103	201	201	201	201
80	28, 69, 49, 104	155	155	155	155

*Coupled LVTP-7 Vehicles
**Coupled M113-A1 Vehicles

TABLE IV. SOFT SOIL VEHICLE PERFORMANCE COMPARISON

Critical Bekker Soils

DATA	VARIABLE			LVTP-7	M113-A1	LVTP-77*	M226**
Gross Vehicle Weight	GVW			51,984	22,600	103,968	45,200
Track Length	TL			152	105	304	210
Track Width	TW			21	15	21	15
Track Thickness	T			2	2	2	2
Road Wheel Radius	R			13	12	13	12
No. of Road Wheels	NBC			12	10	24	20
Ground Clearance	XC			16	16	16	16
SCENARIO SEGMENT	K_c	K_ϕ	n	MOTION RESISTANCE: POUNDS/TON @ SINKAGE: INCHES			
34, 36, 40, 42, 44, 106	6	5.15	.3	339 lb. @ 8.3 in.	425 lb. @ 5.8 in.	278 lb. @ 8.1 in.	305 lb. @ 5.7 in.
38, 107	6	4.03	.3	514 lb. @ 15.51 in.	560 lb. @ 9.7 in.	445 lb. @ 14.4 in.	433 lb. @ 9.5 in.
97, 98	6	3.04	.45	331 lb. @ 11.9 in.	446 lb. @ 8.9 in.	256 lb. @ 11.7 in.	311 lb. @ 8.8 in.
73, 75, 101, 110	6	2.56	.45	391 lb. @ 15.5 in.	502 lb. @ 11.5 in.	307 lb. @ 13.7 in.	358 lb. @ 11.3 in.

*Coupled LVTP-7 Vehicles
**Coupled M113-A1 Vehicles

TABLE V. LAND PERFORMANCE SUMMARY

VEHICLE DATA	M-113	CCRV	P-7	Coupled Vehicle	Articulated Vehicle
General					
GVW (lbs)	22,700	46,000	52,000	106,500	54,000
LOA (ft.)	16	35	26	54	33
Pitch up/down (Deg.)	---	25/28	---	30/30	30/30
Yaw L/R (Deg.)	---	30/30	---	30/30	34/34
Max pitch up attitude on land front/rear	0	+20/-5	0	+21/-9	+25/-5 (est)
Max trim up in water front/rear	0	+14/-11	-1.5	+14/-16	N/A
Performance					
Turning Radius (to wall, ft)	24	41	15	61	35
Step obstacle height (ft.)	2	5	3	7	4
Trench Width (ft.)	5.5	11	8	14	14
σ=25°, Short Slope (%)	45	60	39	100	58
σ=34°, Water exit (%)	47	67	N/A	67	67 (est)
Vehicle cone index	15	15	15	15	13
Soft soil DBP (lb./lb.) calculated @ CI = 20	.21	.21	.25	.25	.32
@ CI = 40	.57	.57	.57	.57	.58
Cross Country Ride @ 6 watts (mph)	9	16	50 to 75% Increase in Speed Expected		
Corridor Turning (ft.)	12	19	16.5	27.5	22
Dash Time		1 Unit Disabled		1 Unit Disabled	Full/Aux./Rear unit only, Aux power
Speed reached in 15 sec. (mph)	27	16	24	14	34/09/11
in 30 sec. (mph)	31	20	28	16	45/09/13
Time to go 500 ft (sec.)	18	25	19	28	15/43/32
1000 ft (sec.)	29	41	31	48	21/81/59

TABLE VI

HYDRODYNAMIC MODEL PARTICULARS

(Values given as full-size equivalents)

Vehicle	Length, ft	26.0
	Beam, ft	10.6
	Depth, ft	8.2
Loading:		
	Combat Equipped, lb	42,377
	Combat Loaded, lb	52,377
Coupled Vehicles		
	Overall Length, ft	53.2
	Relative Incidence, degrees	15.0

TABLE VII

WATER PERFORMANCE SUMMARY

	STANDARD LVTP-7	COUPLED LVTP-7
Calm water resistance at 8 mph, lb/ton	195	143
Maximum speed in sea state 2, mph	6	10
1/10 highest acceleration at CG, g (6 mph, sea state 2)	0.2	0.22
Significant pitch double amplitude, degrees (6 mph, sea state 2)	12.4	6.8

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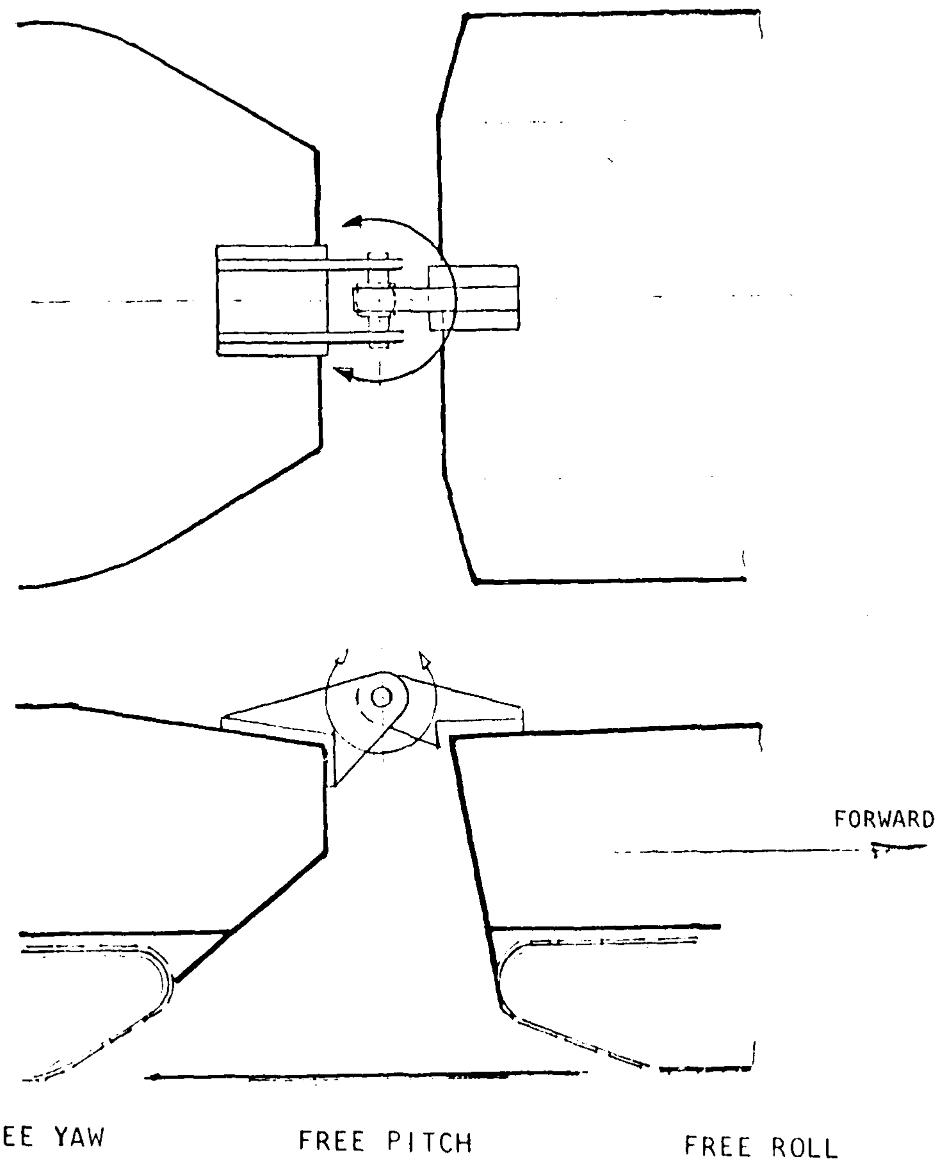
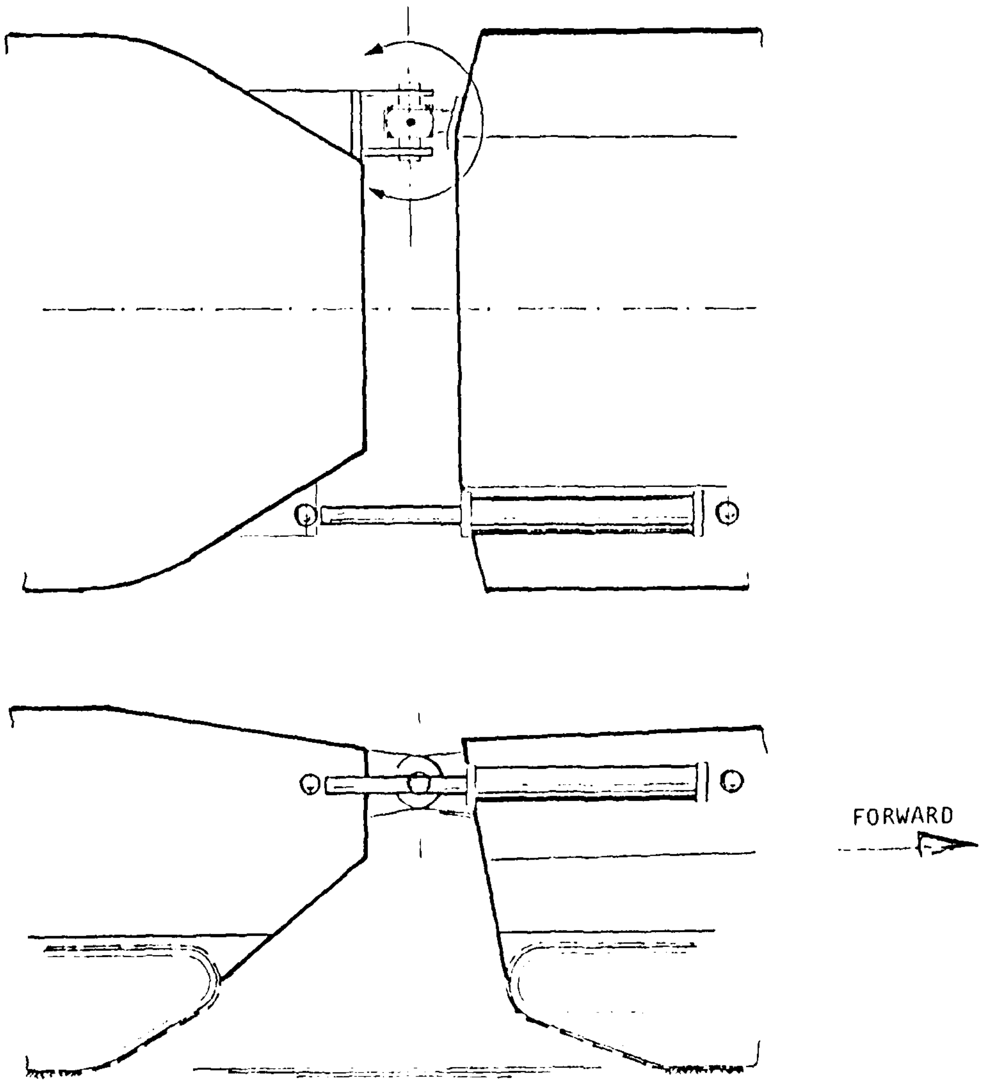


CONCEPT 1. Ball Joint

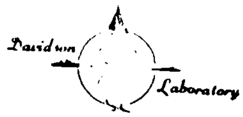
FIGURE 1

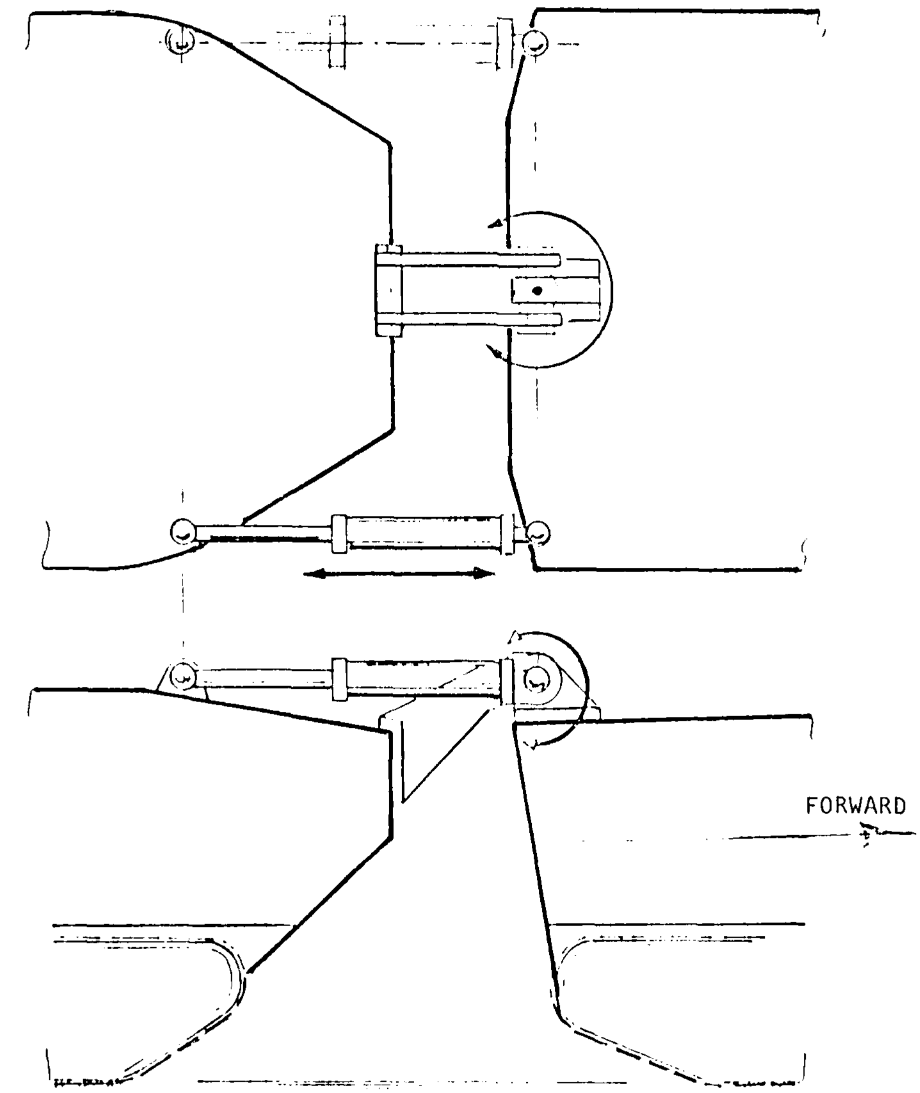


ASSYMETRICAL YAW FREE PITCH LIMITED ROLL

CONCEPT 2. **Off**-Center Ball Joint

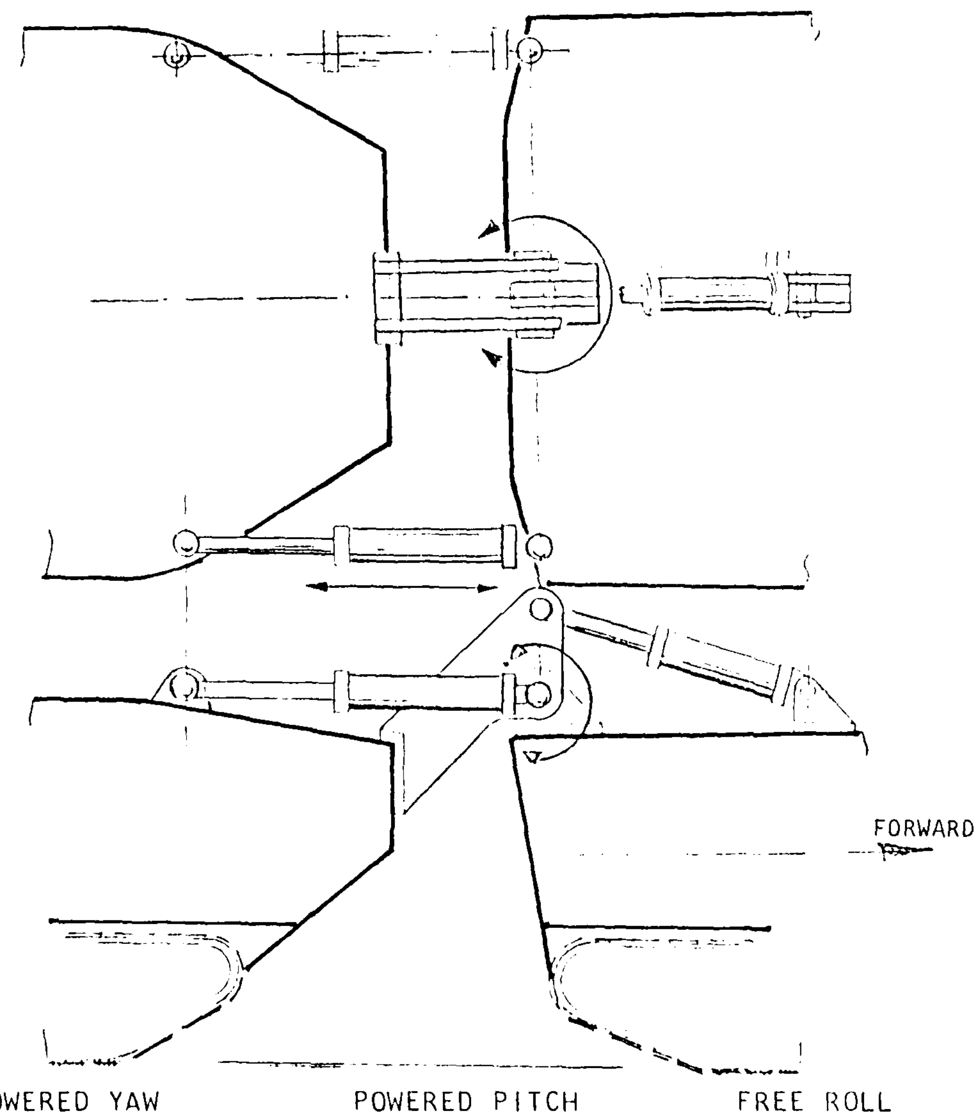
FIGURE 2





CONCEPT 3. Symmetrical Yaw

FIGURE 3



CONCEPT 4. Symmetrical Yaw with Independent Pitch Control

FIGURE 4

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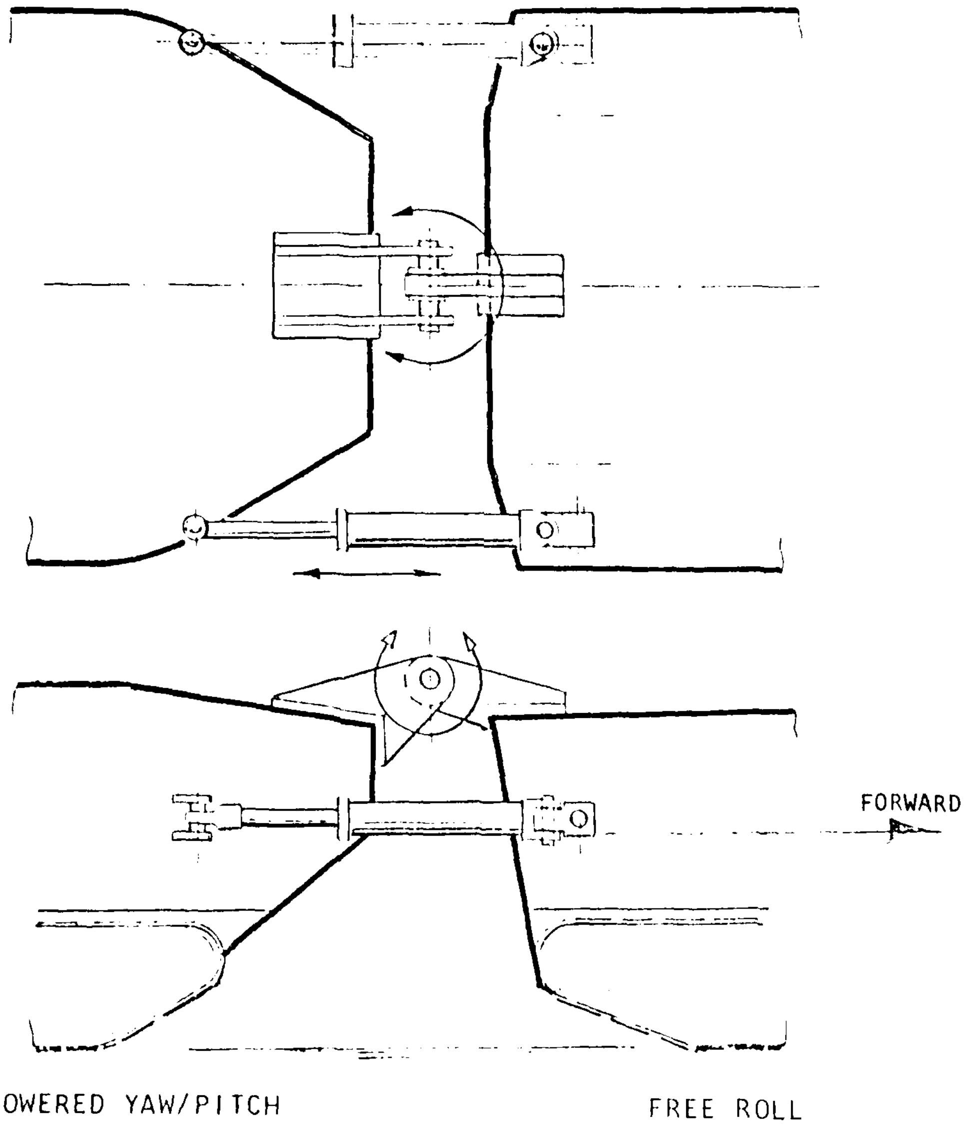

CONCEPT 5. Dependent Yaw and Pitch

FIGURE 5

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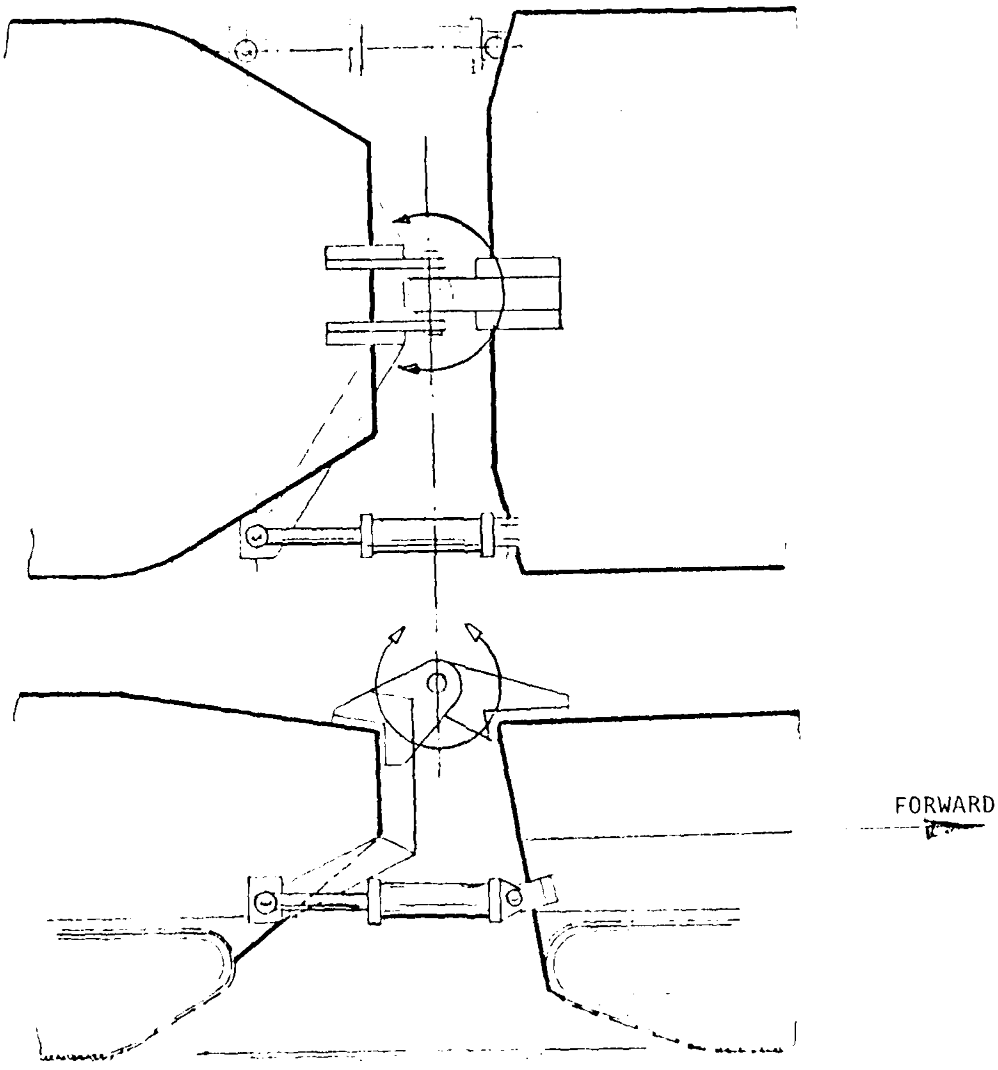
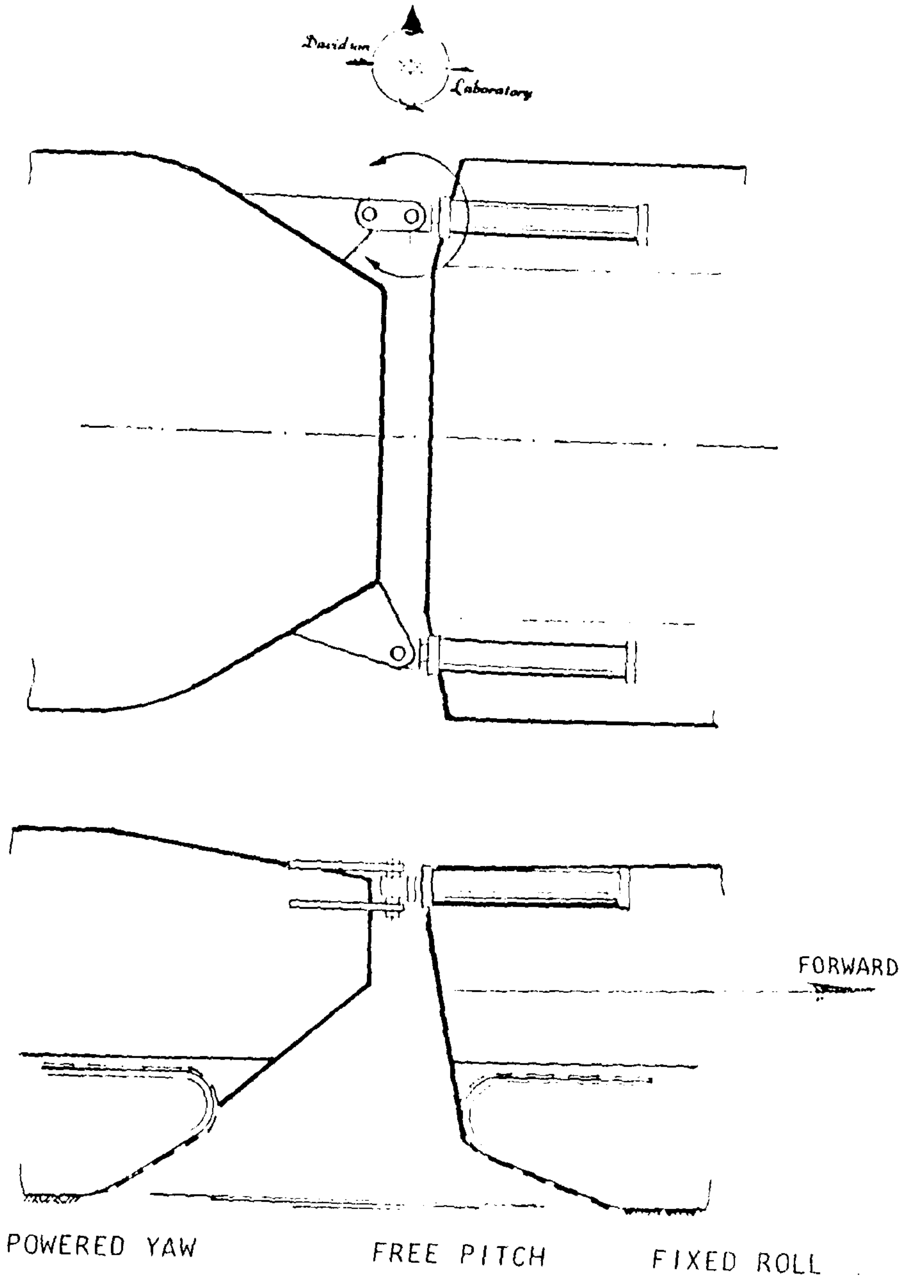


CONCEPT 6. Dependent Pitch and Yaw with Coupling Frame

FIGURE 6



CONCEPT 7. Yaw -- No Roll

FIGURE 7

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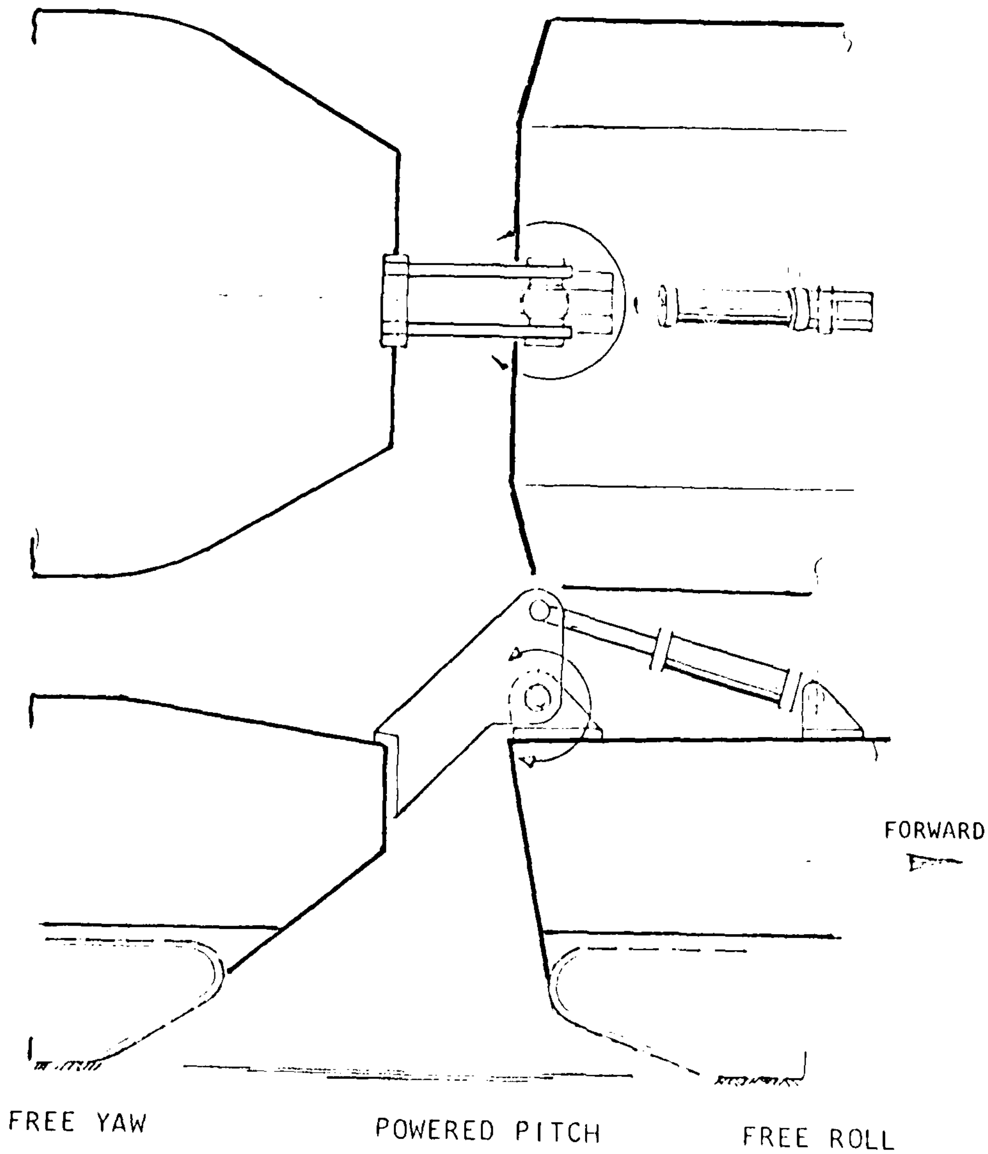
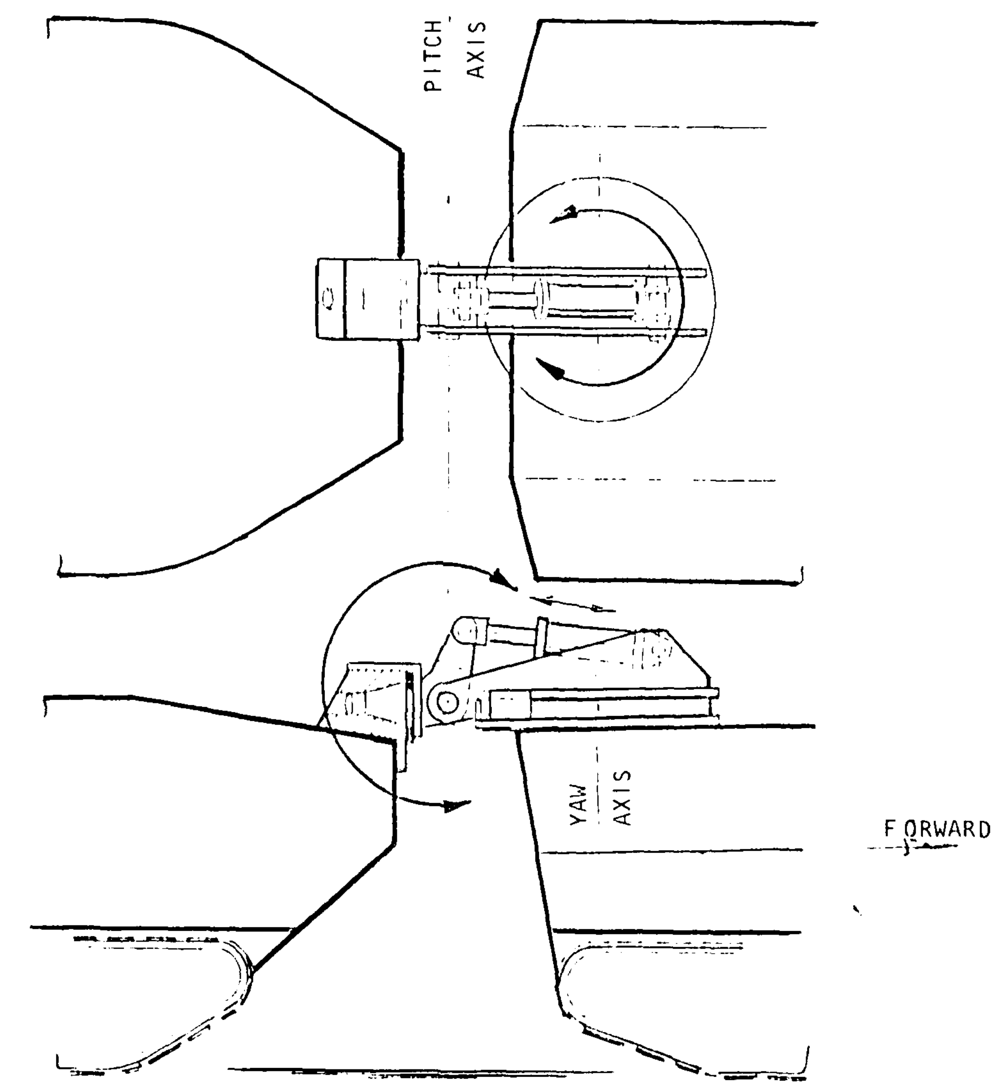


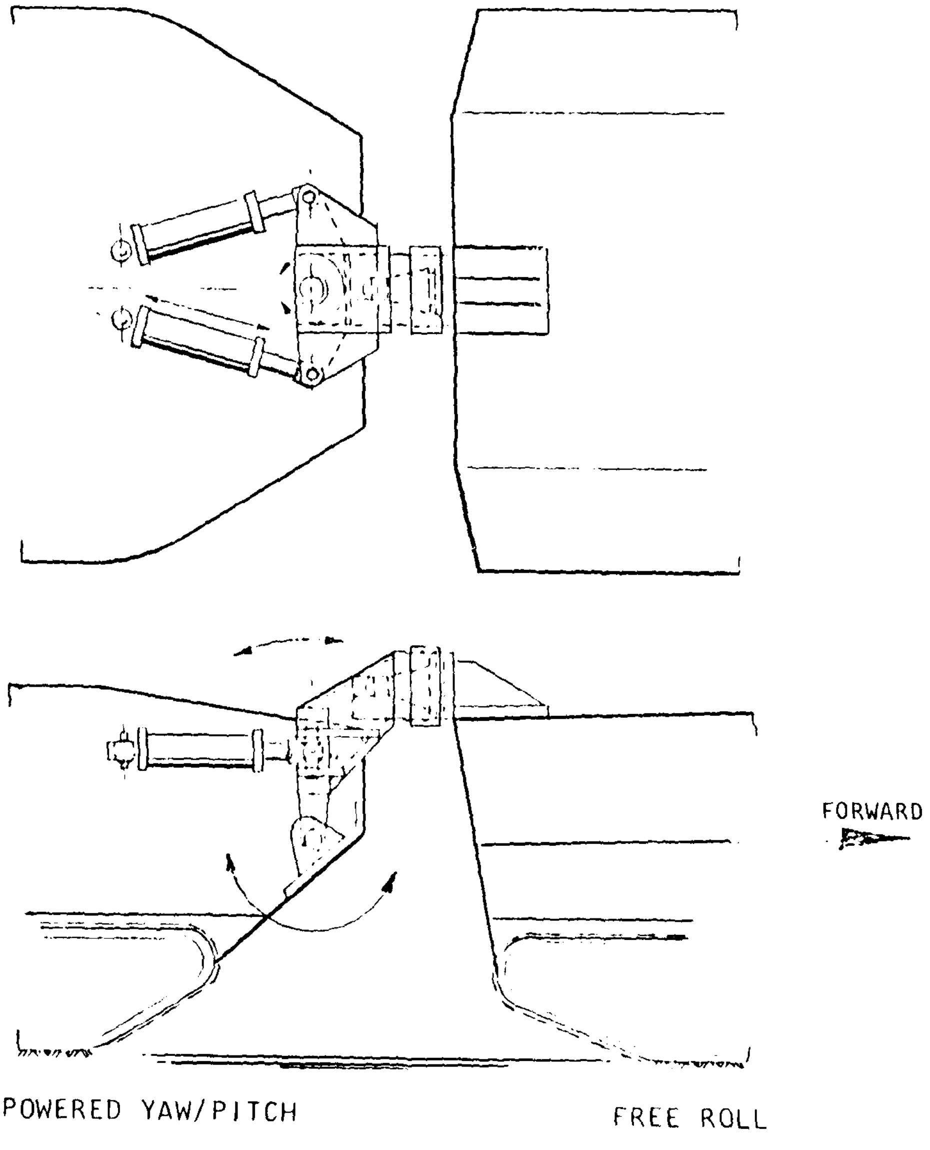
CONCEPT 8. Pitch Only

FIGURE 8



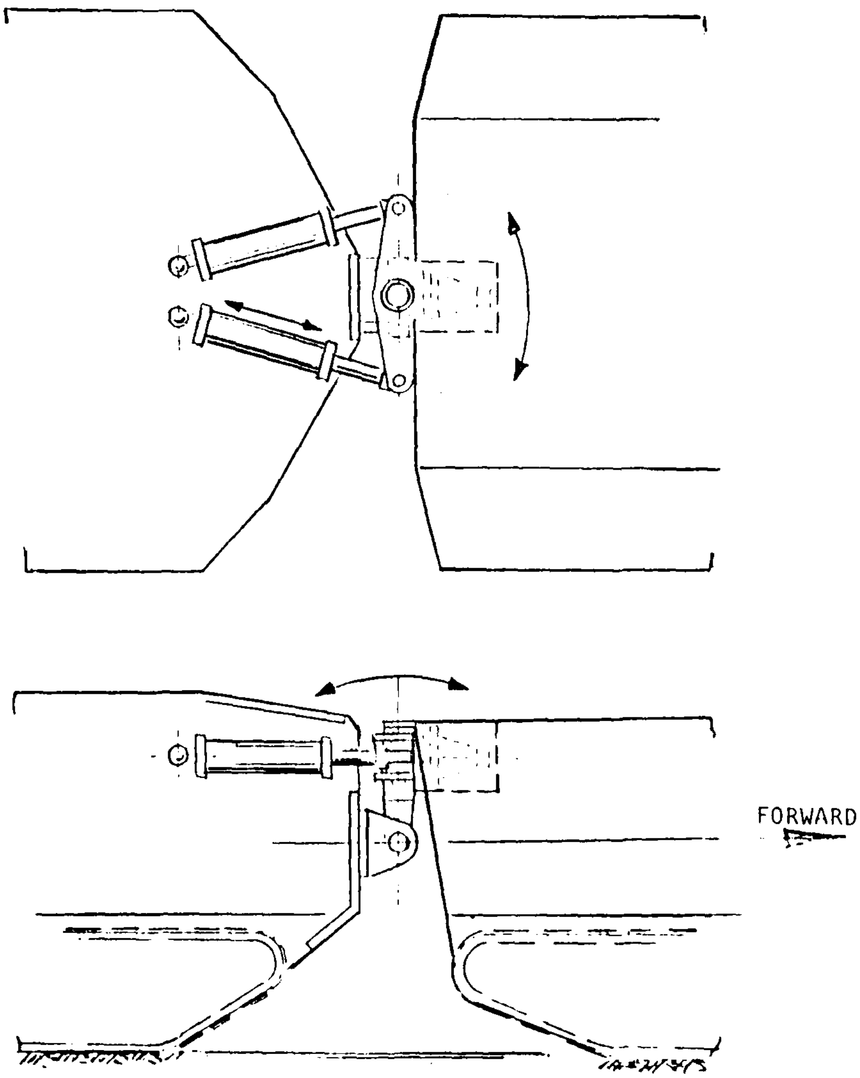
CONCEPT 9. Turn Table

FIGURE 9



CONCEPT 10. Trunnion Mount

FIGURE 10



POWERED YAW/PITCH

FREE ROLL

CONCEPT 11. Trunnion Mount, Internal Coupler

FIGURE 11

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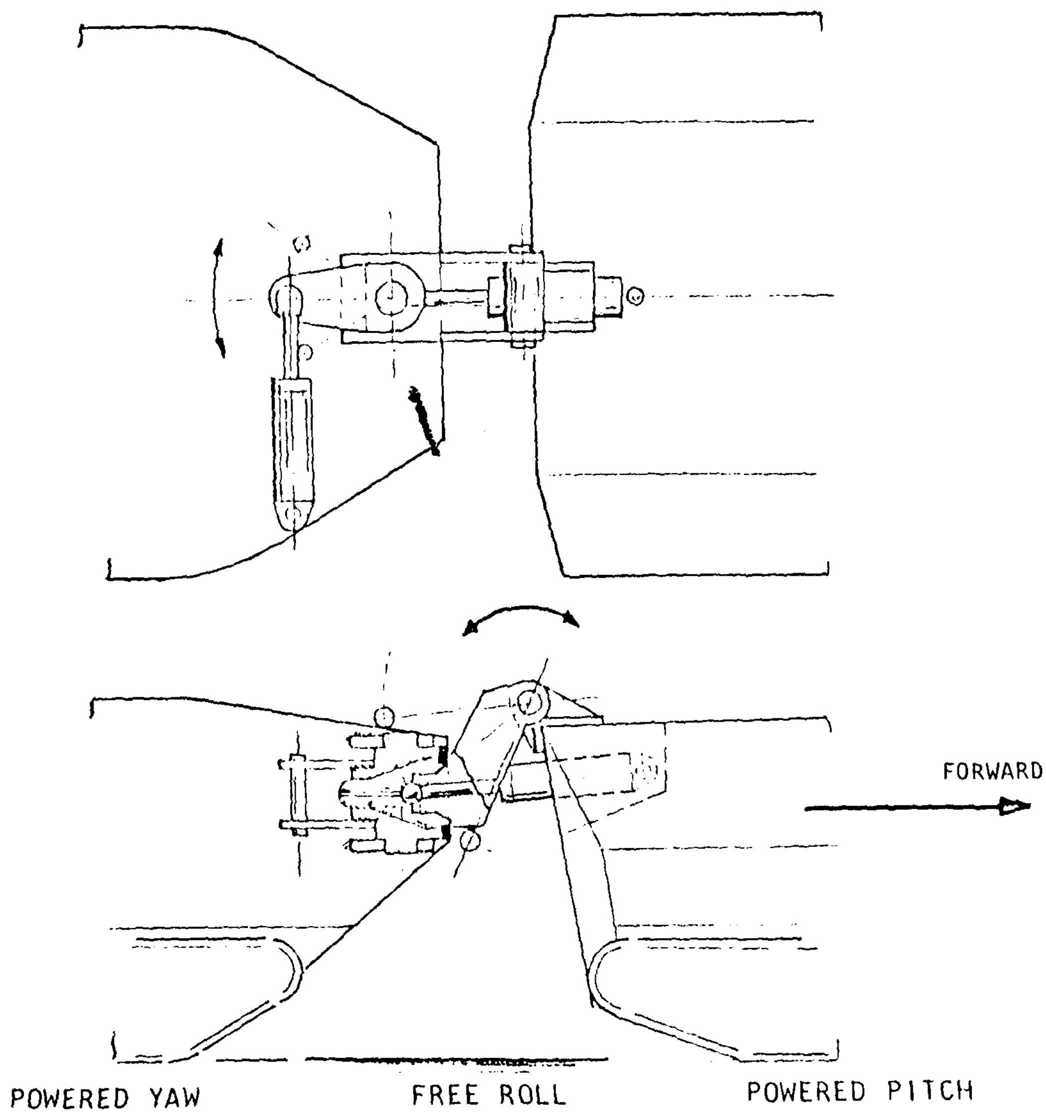


CONCEPT 12. Split Pitch and Yaw

FIGURE 12

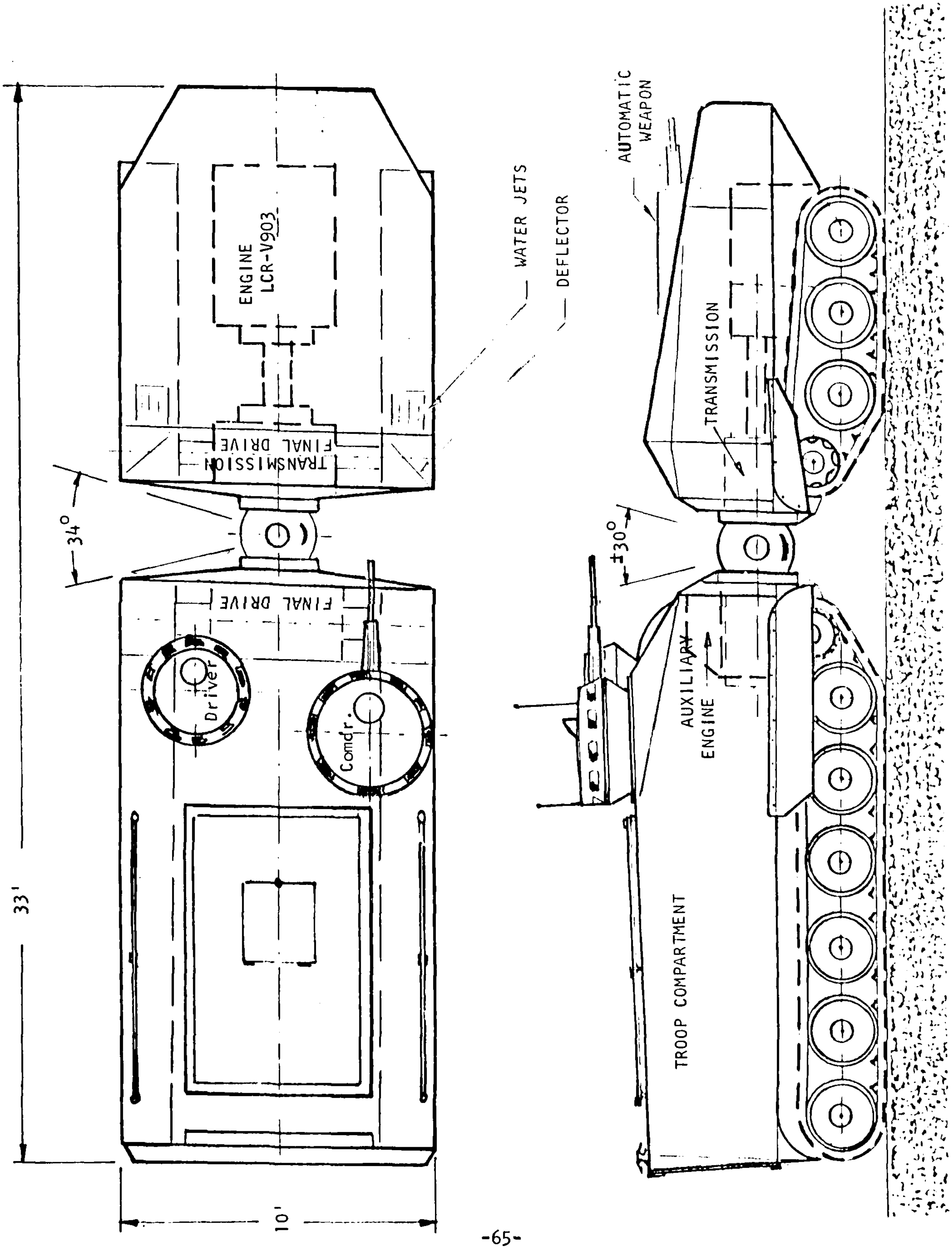


FIGURE 13. Articulated Vehicle, Powered Through Joint

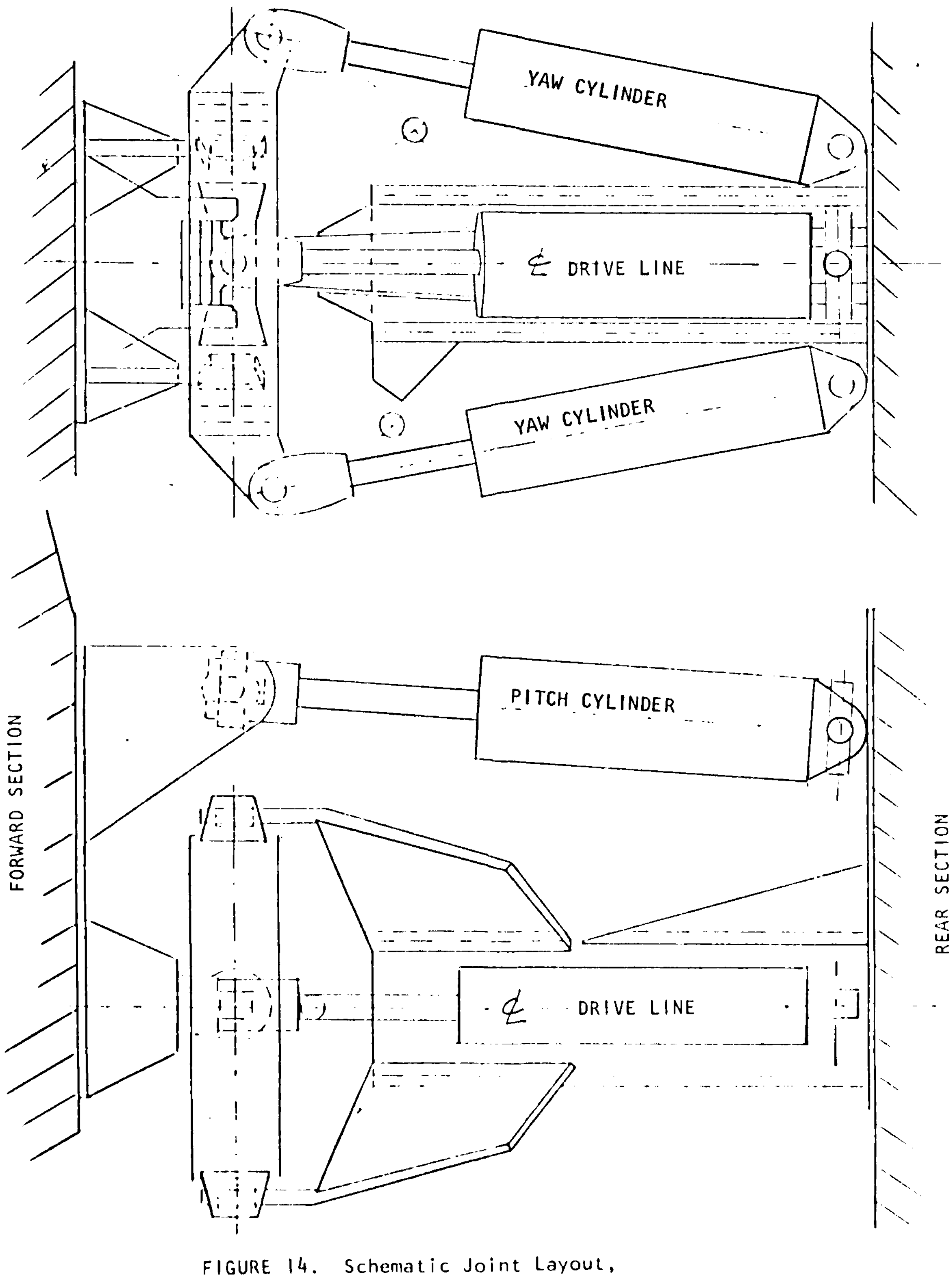


FIGURE 14. Schematic Joint Layout, Articulated Vehicle

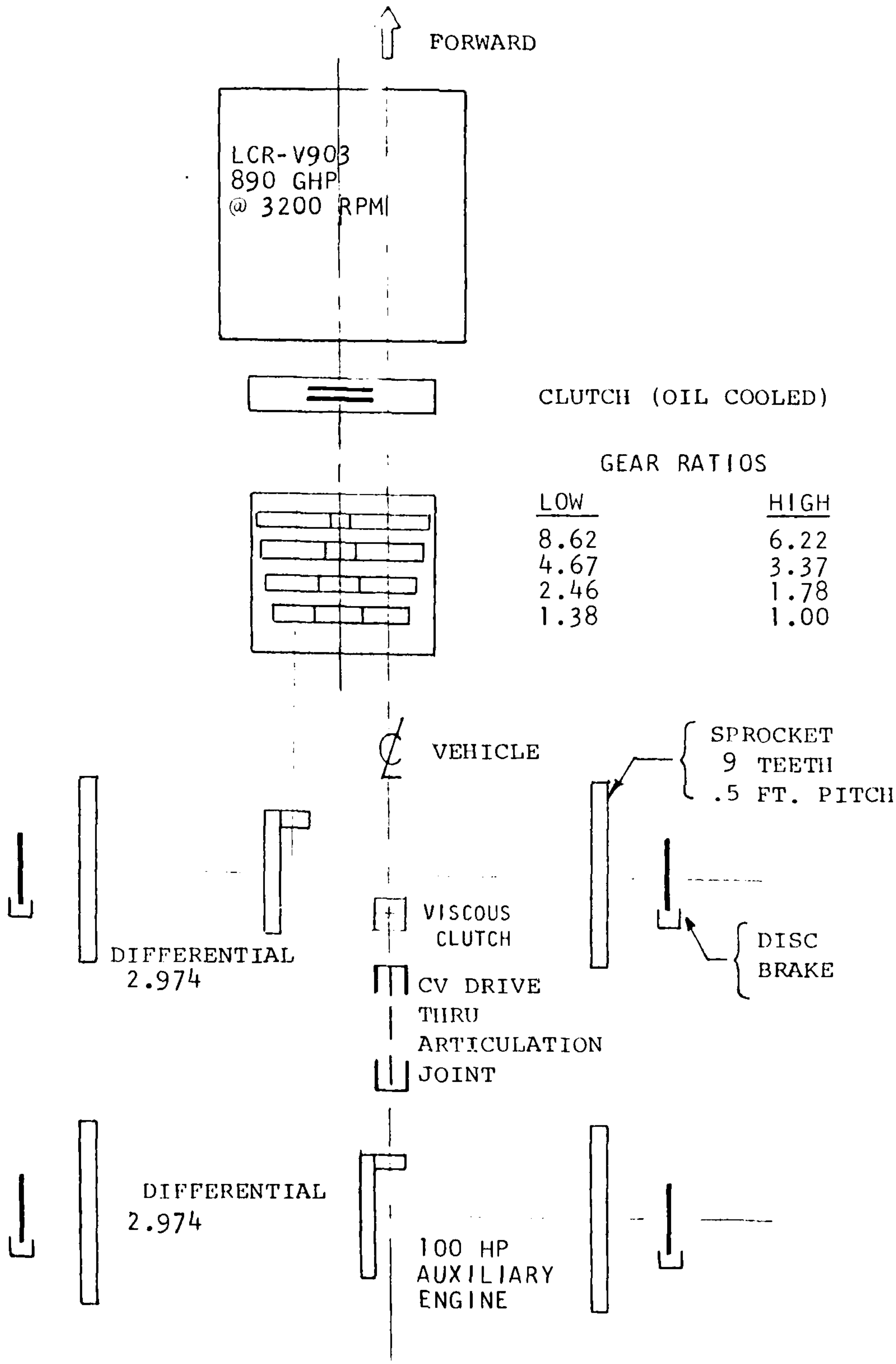


FIGURE 15. Conceptual Powertrain Schematic for the Articulated Vehicle

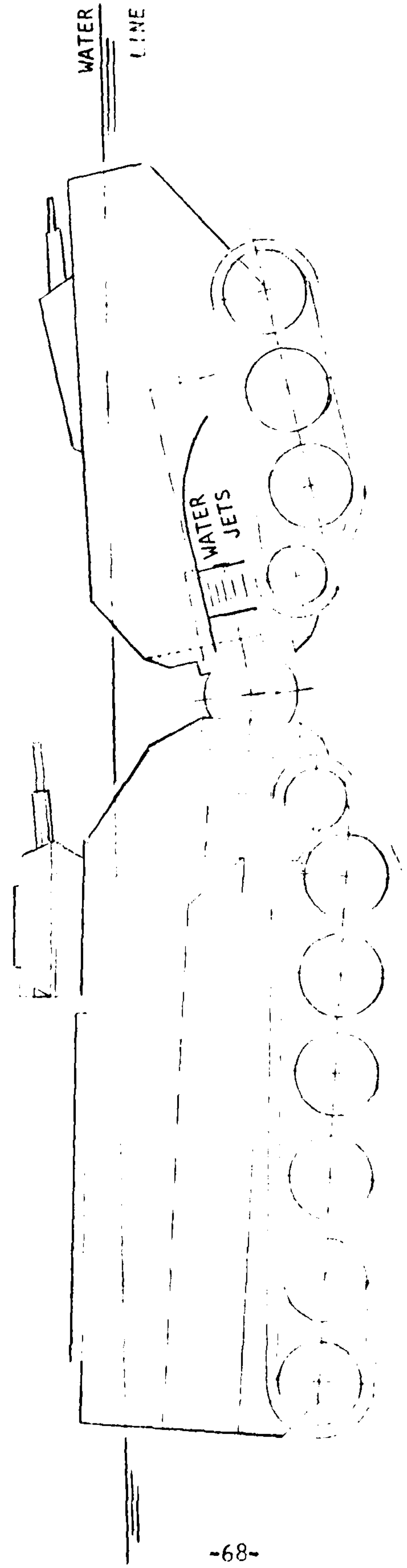


FIGURE 16. Articulated Vehicle
Floating Trim 15° up

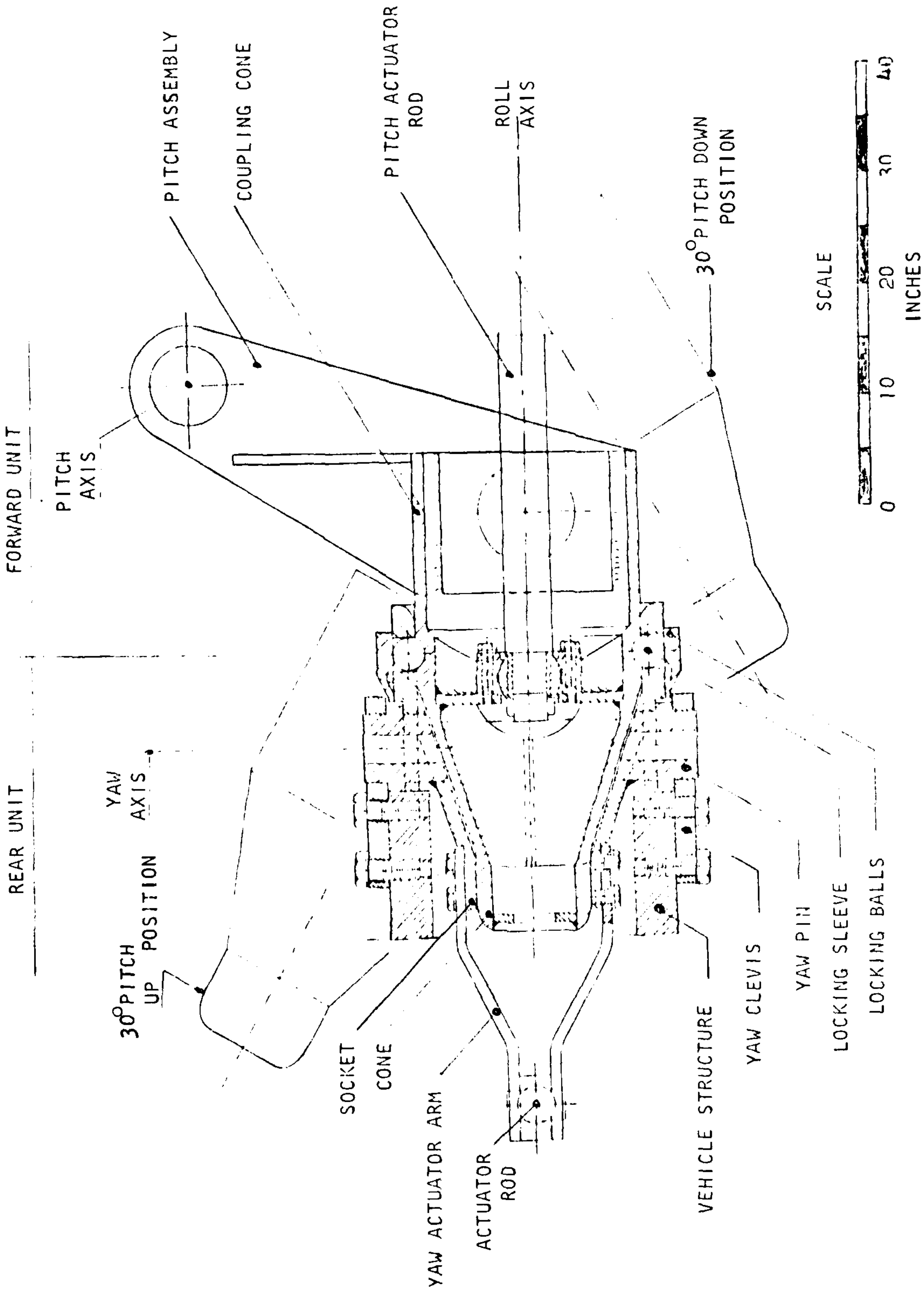


FIGURE 17. COUPLING JOINT

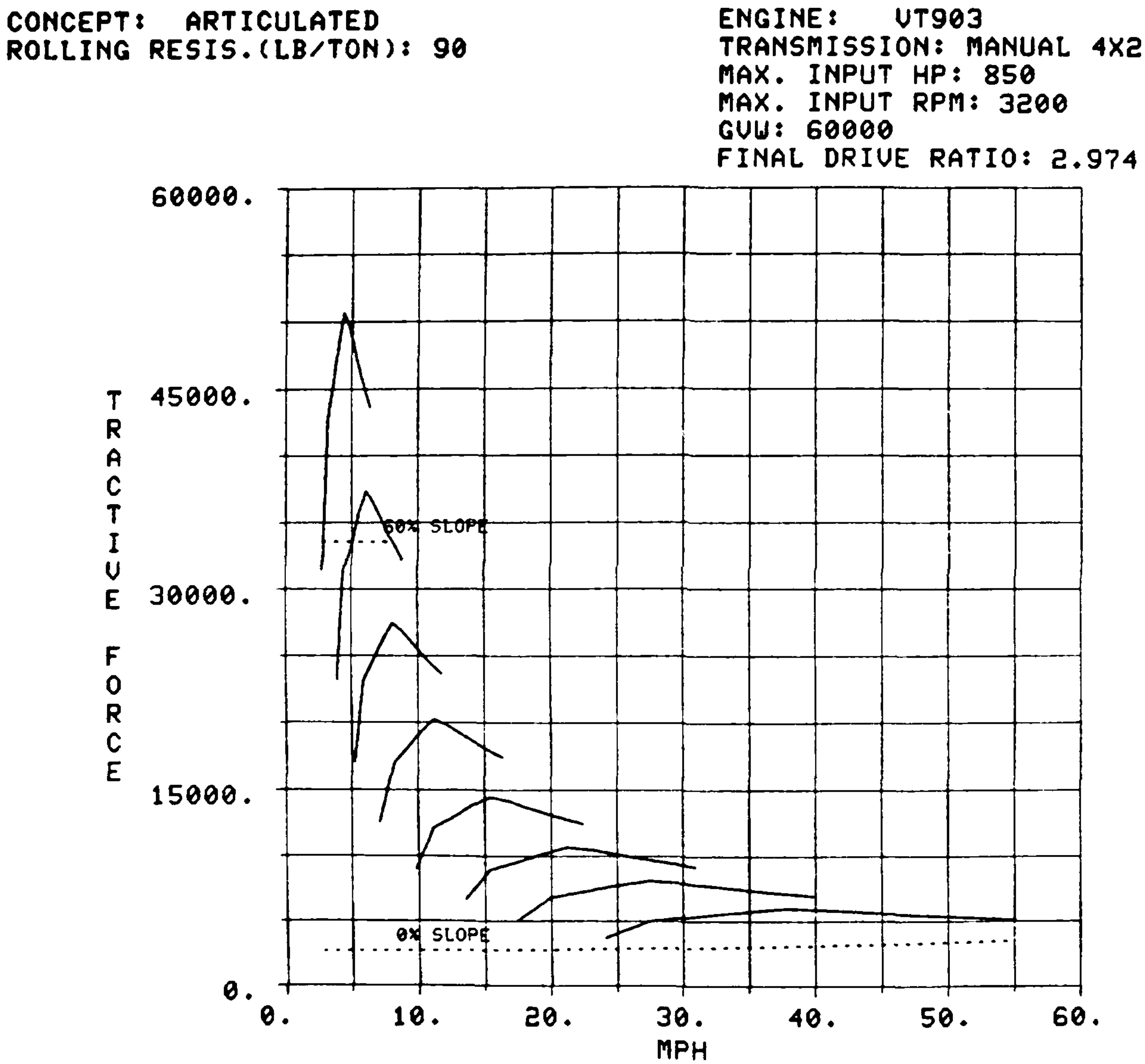


FIGURE 18. Tractive Effort, Articulated Vehicle

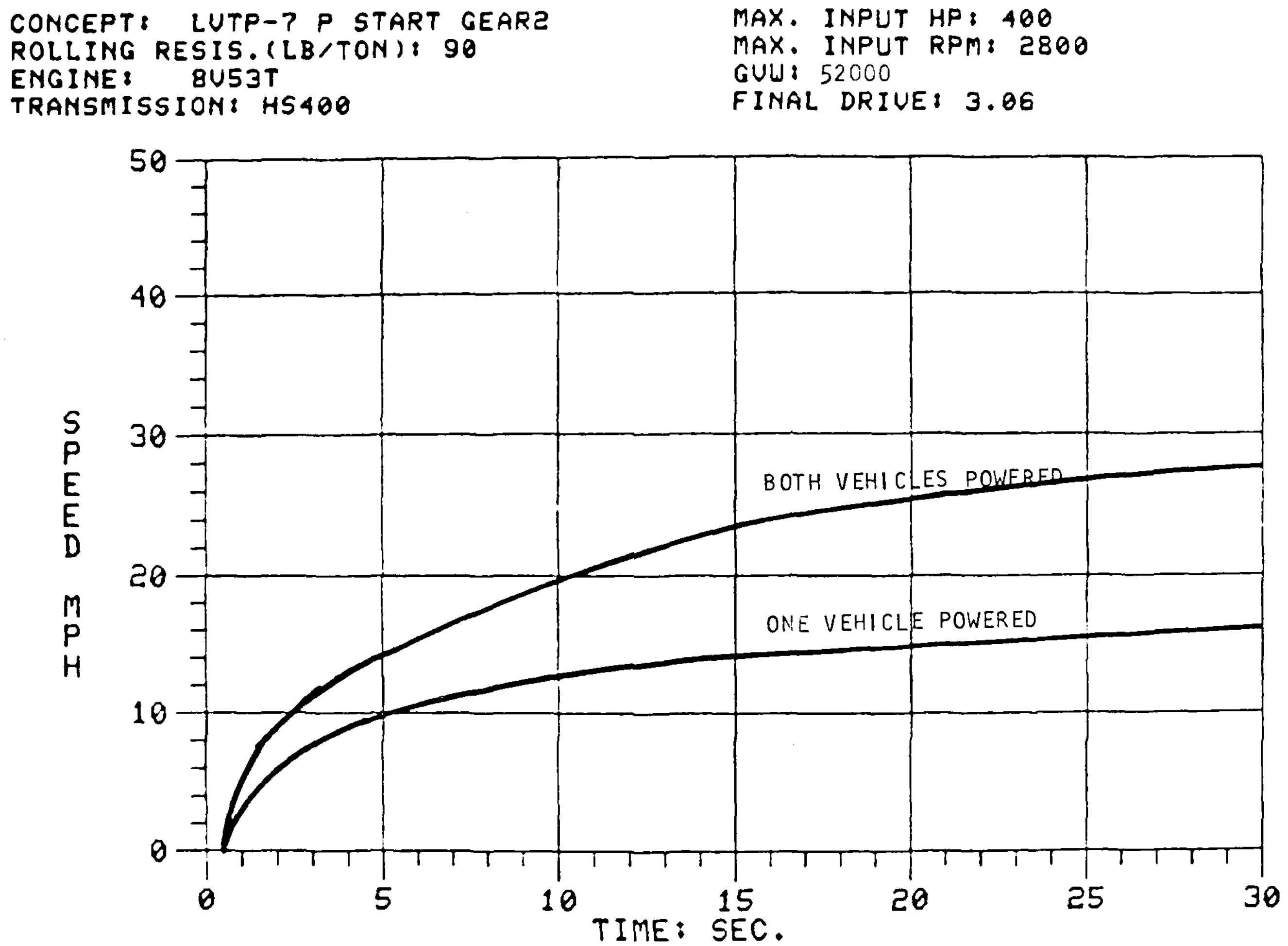


FIGURE 19. Sample Acceleration, Coupled Vehicles
Full Power Compared to One Unit Disabled

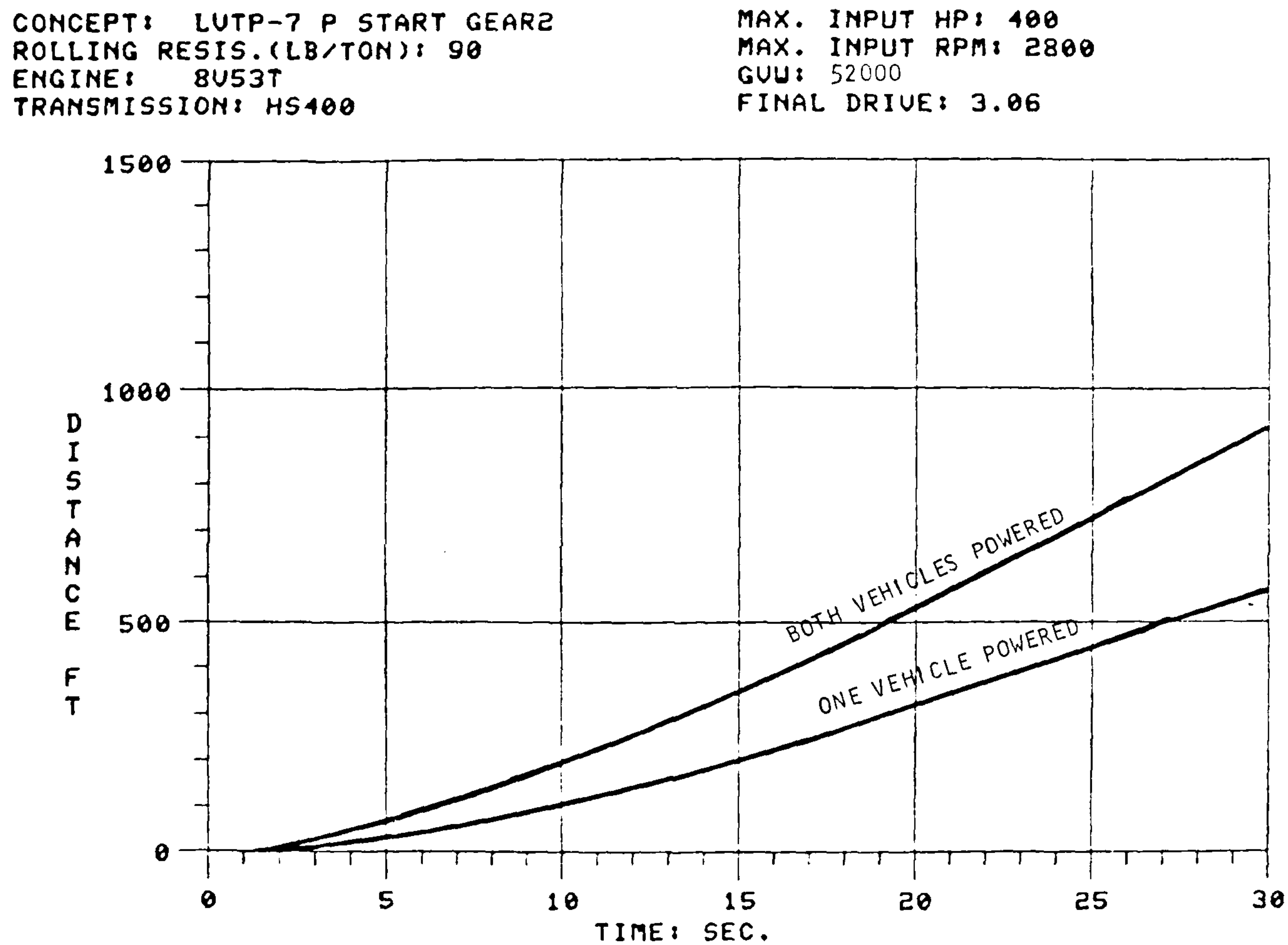
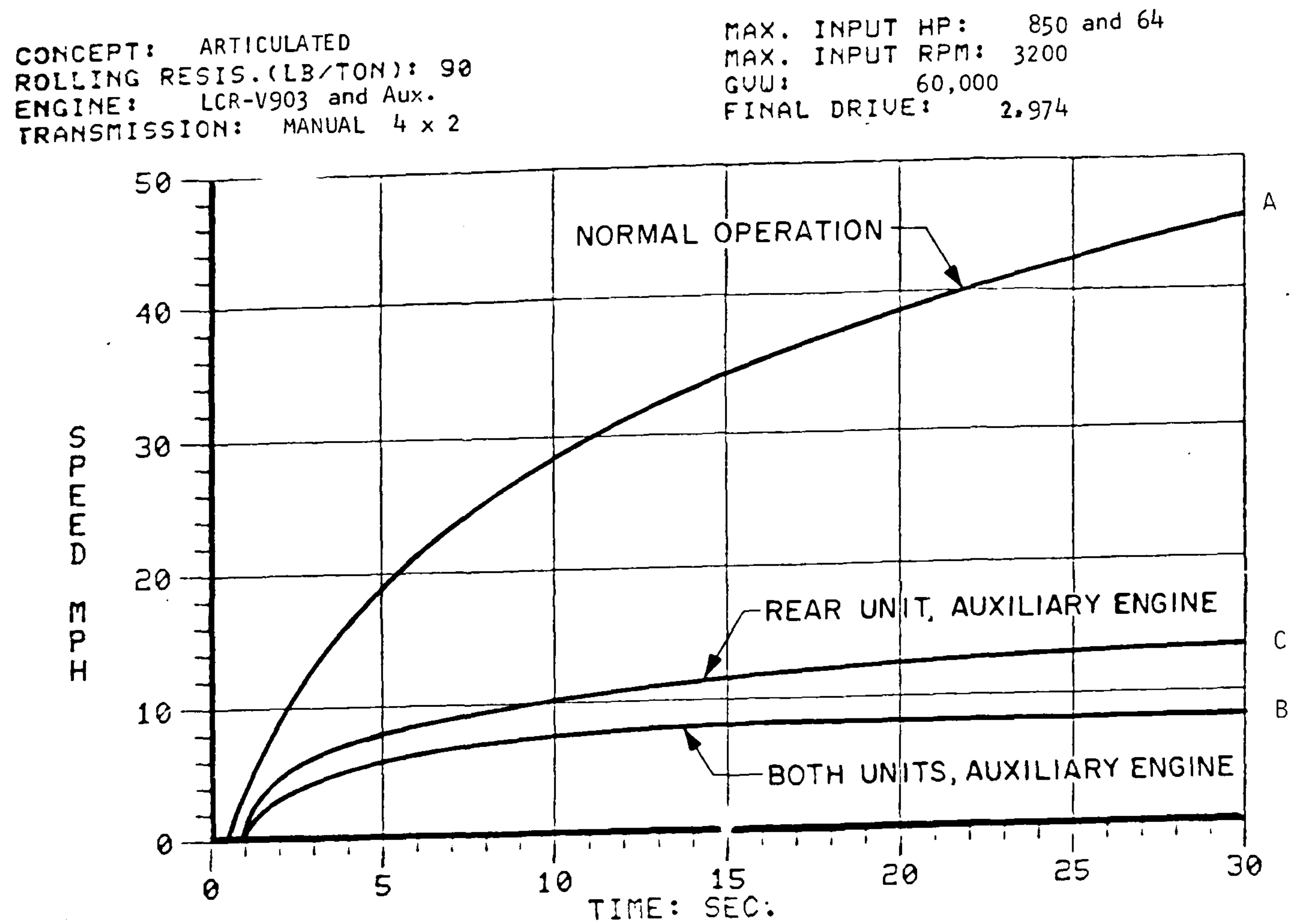
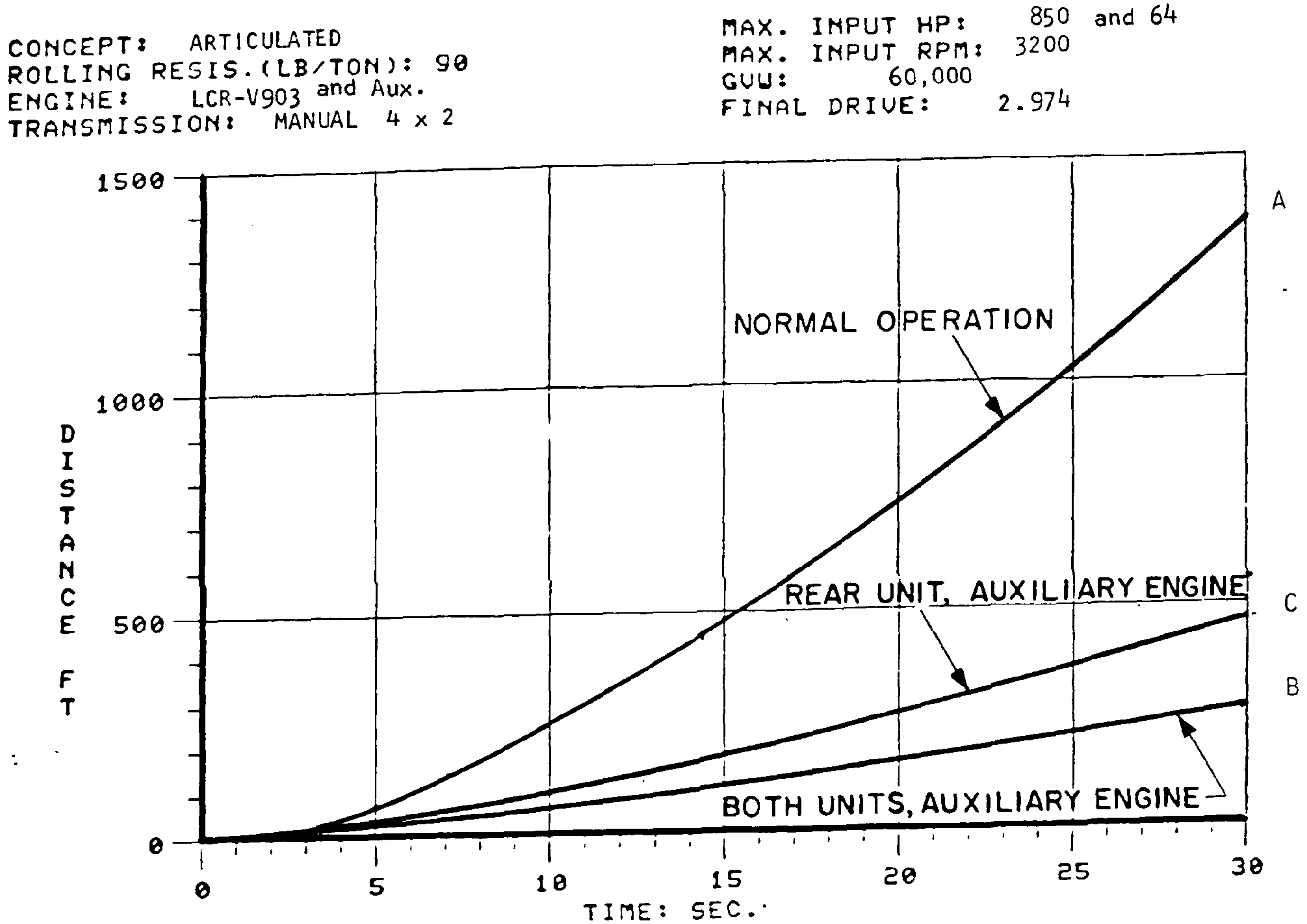


FIGURE 20. Sample Dash Time, Coupled Vehicles
Full Power Compared to One Vehicle Disabled



A. Full power of main engine - 850 HP (NET)
B. Powered by auxiliary engine only - 64 HP (NET)
C. Forward unit jettisoned, rear unit only powered by auxiliary engine

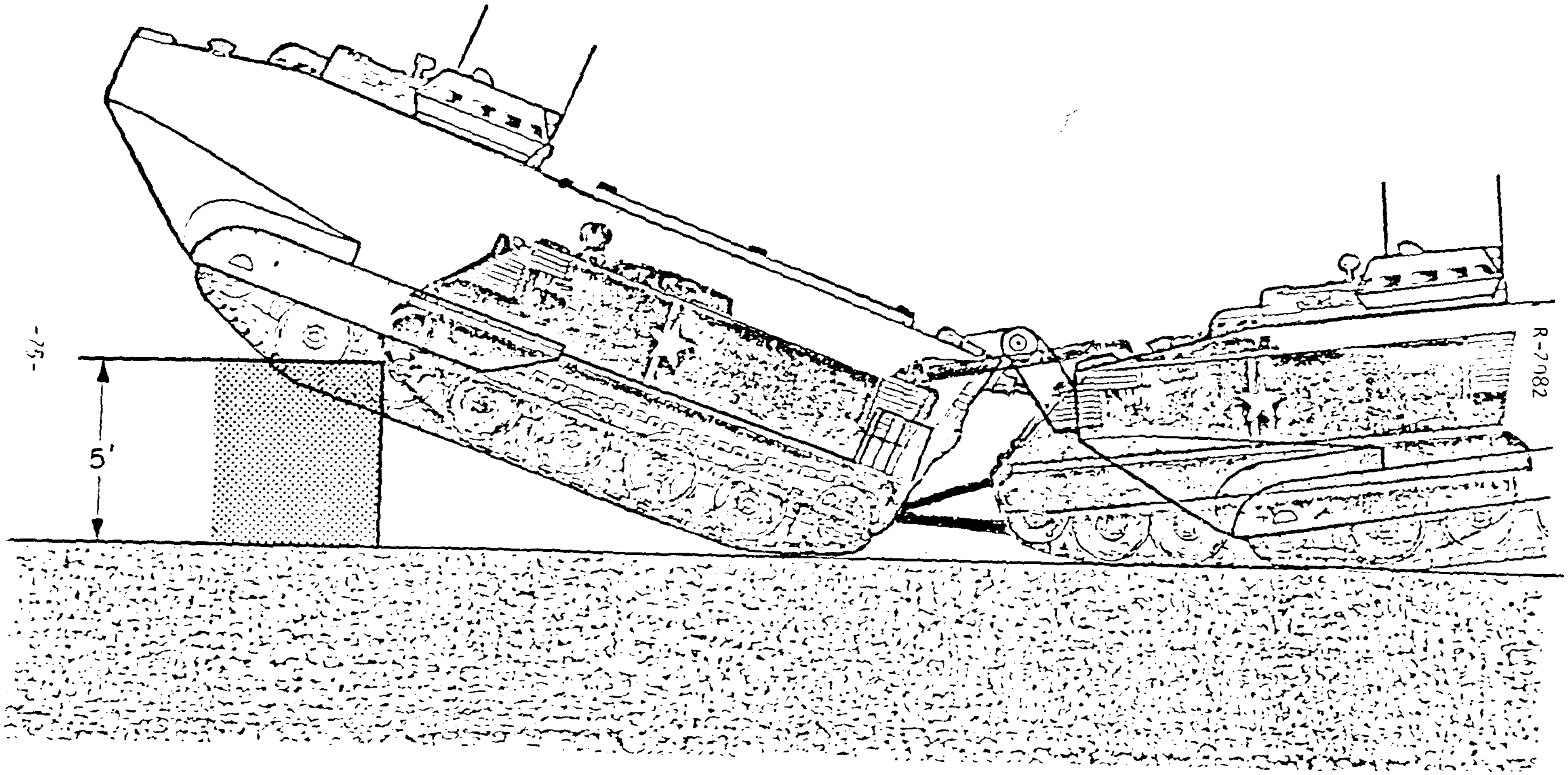
FIGURE 21. Acceleration, Articulated Concept



A. Full power of main engine - 850 HP (NET)
B. Powered by auxiliary engine only - 64 HP (NET)
C. Forward unit jettisoned, rear unit only powered by auxiliary engine

FIGURE 22. Dash Time, Articulated Concept

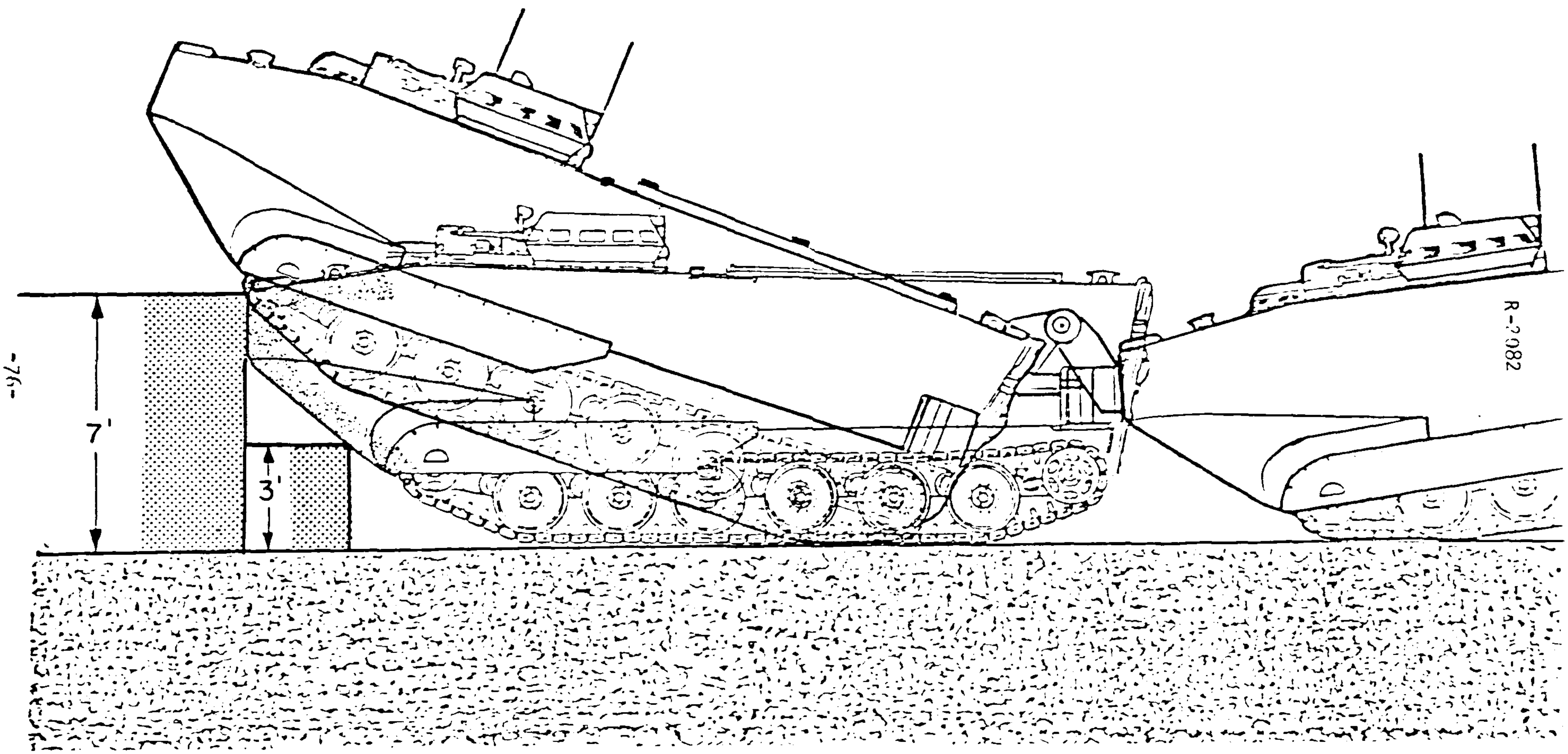
Davidson Laboratory
Stevens Institute of Technology



STEP OBSTACLE

FIGURE 23. Coupled LVT Compared to Coupled M-113

Davidson Laboratory
Stevens Institute of Technology



STEP OBSTACLE

FIGURE 24. Coupled Compared to Single LVT

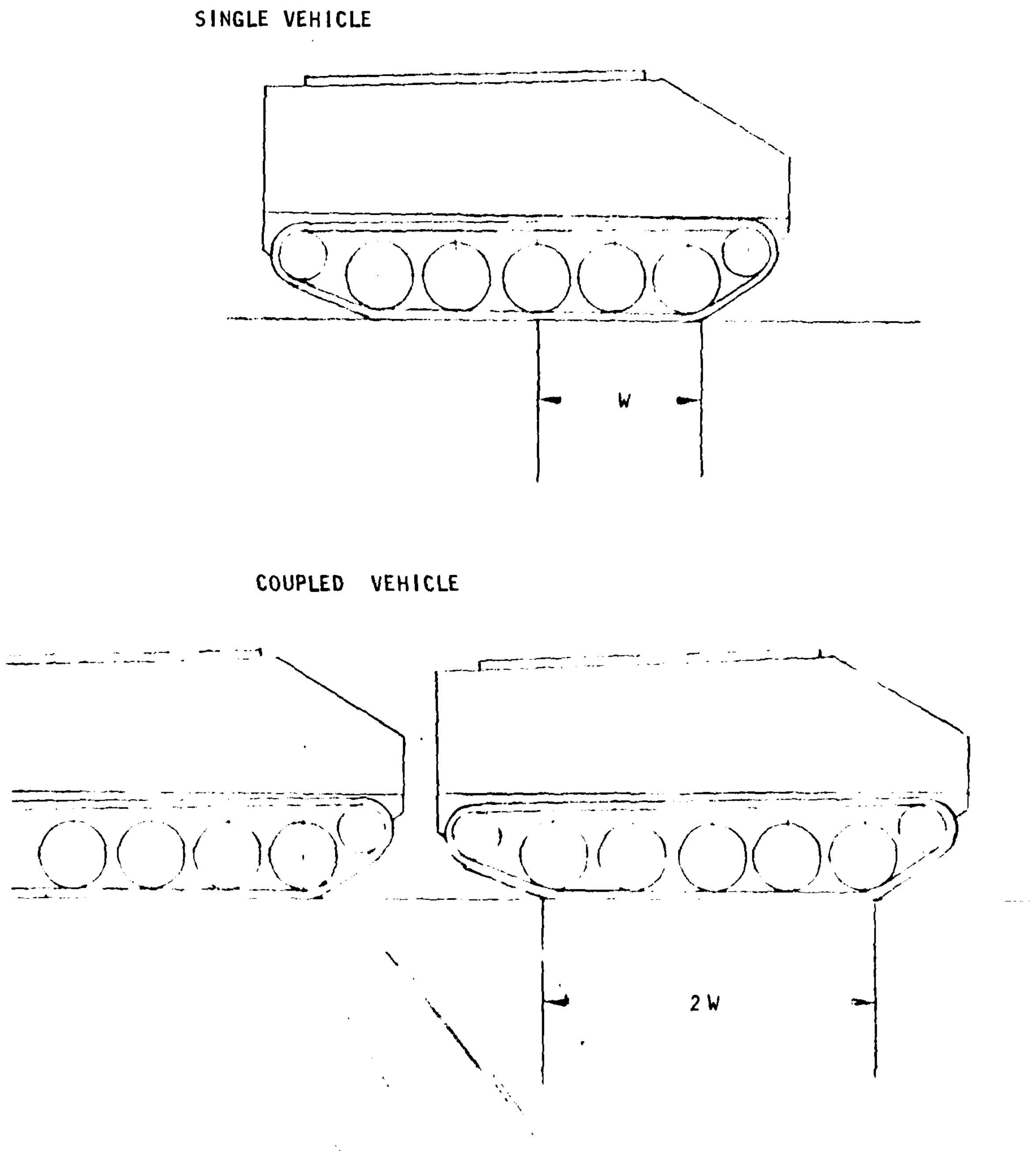
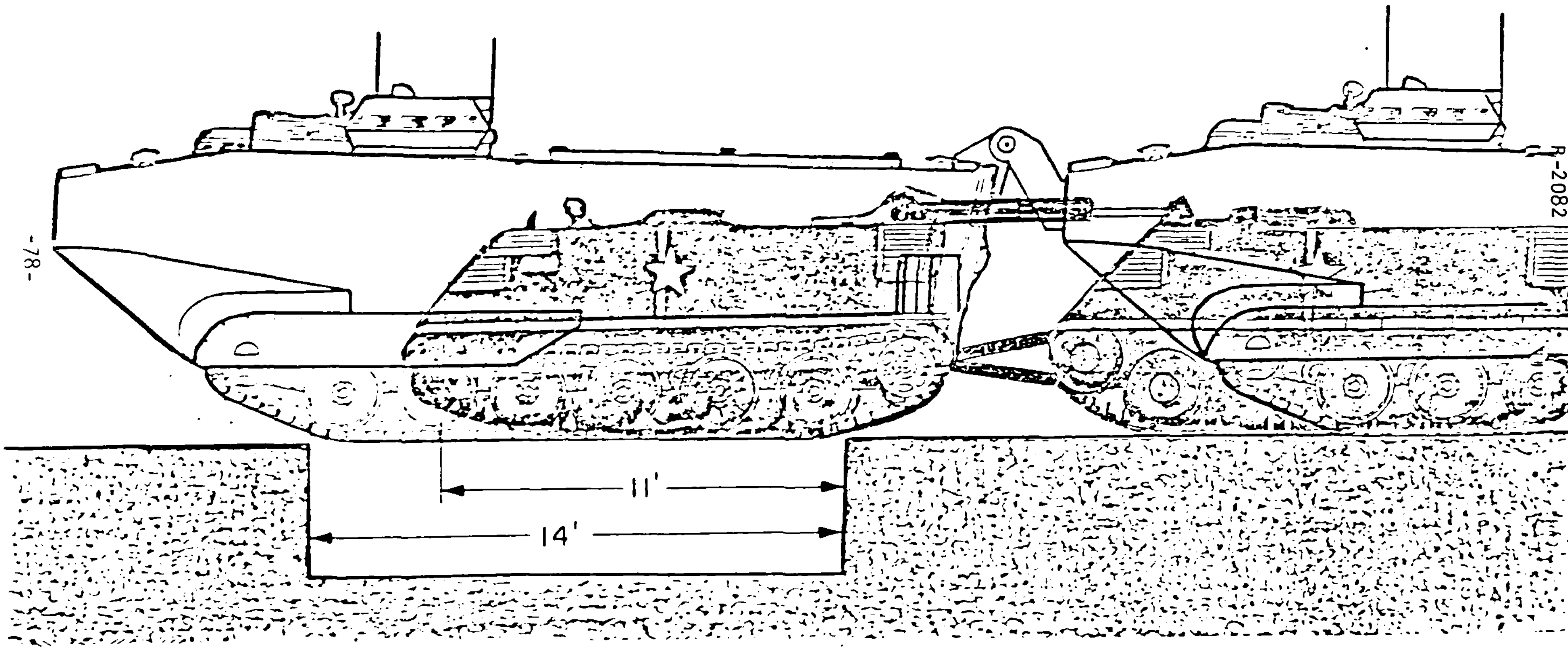
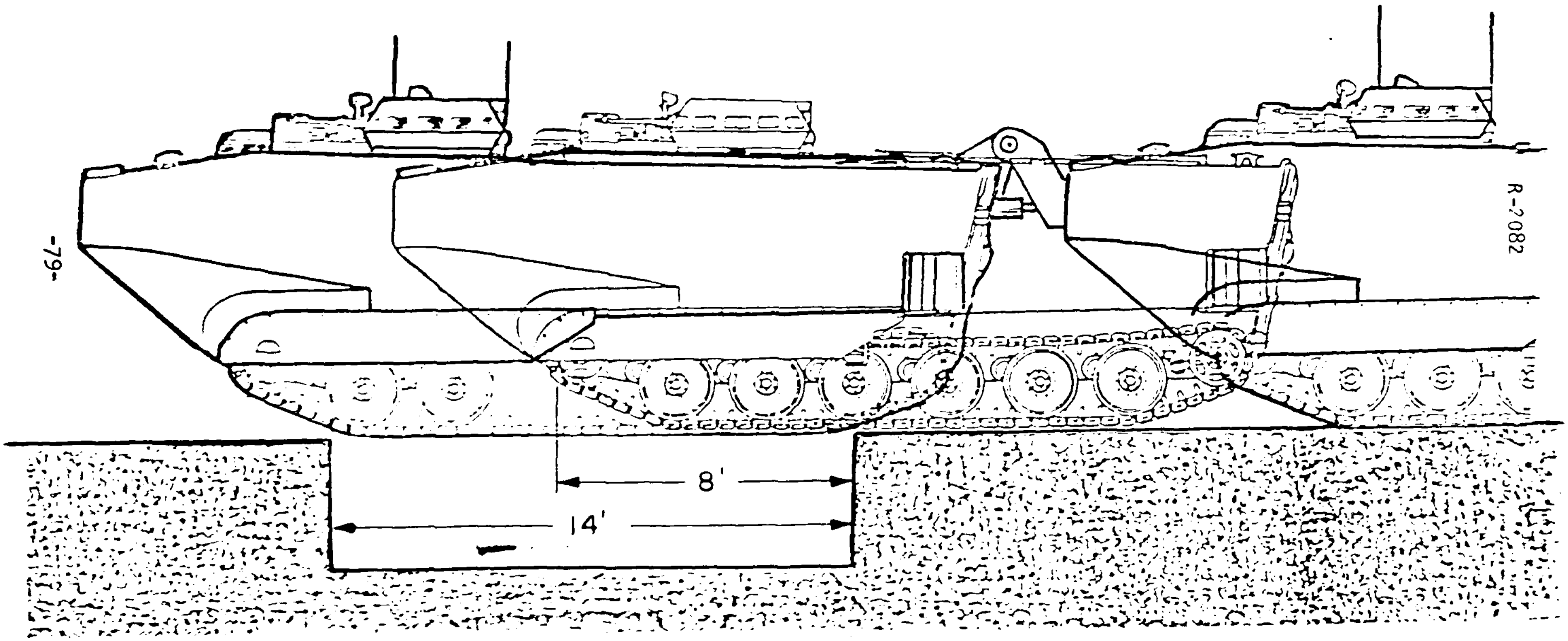


FIGURE 25. Trench Crossing, Basic Geometry



TRENCH CROSSING

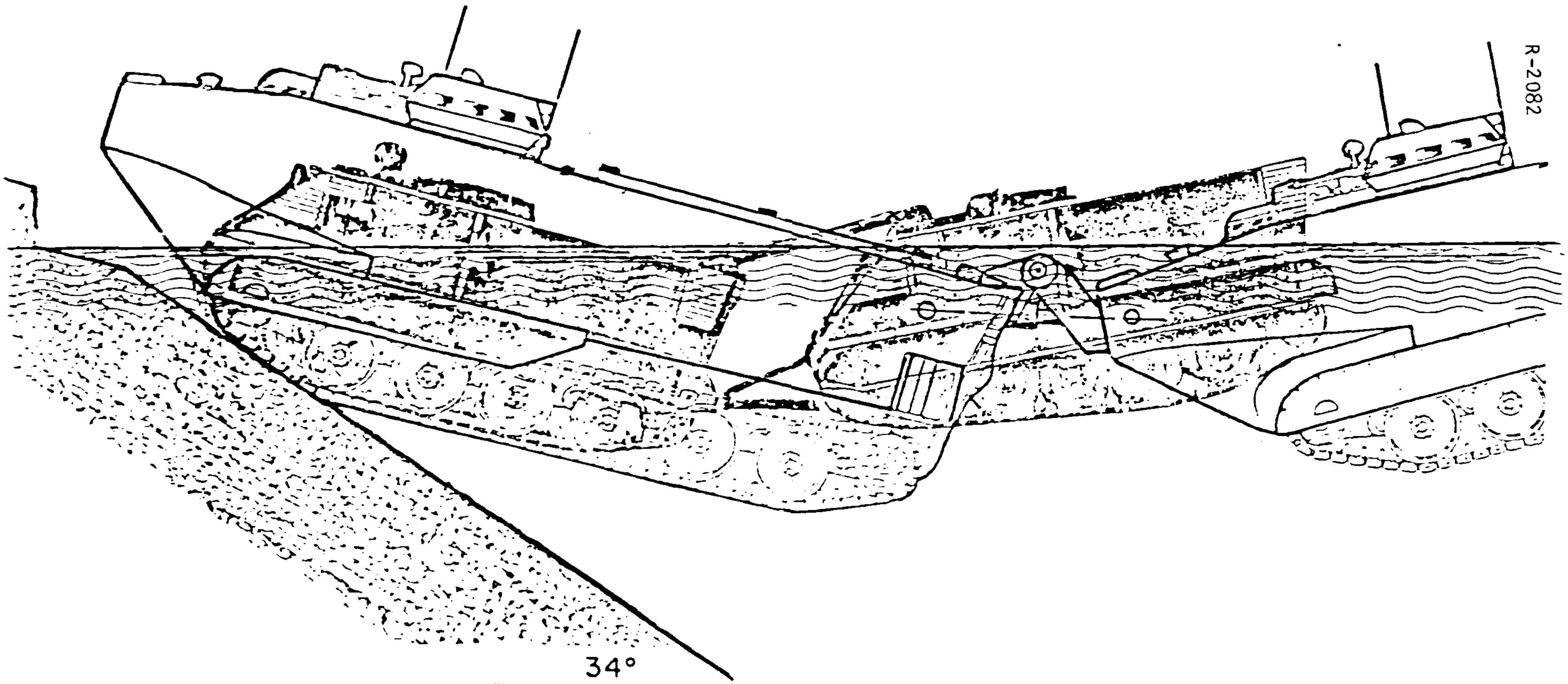
FIGURE [illegible]. Coupled LVT Compared to Coupled M-113



TRENCH CROSSING

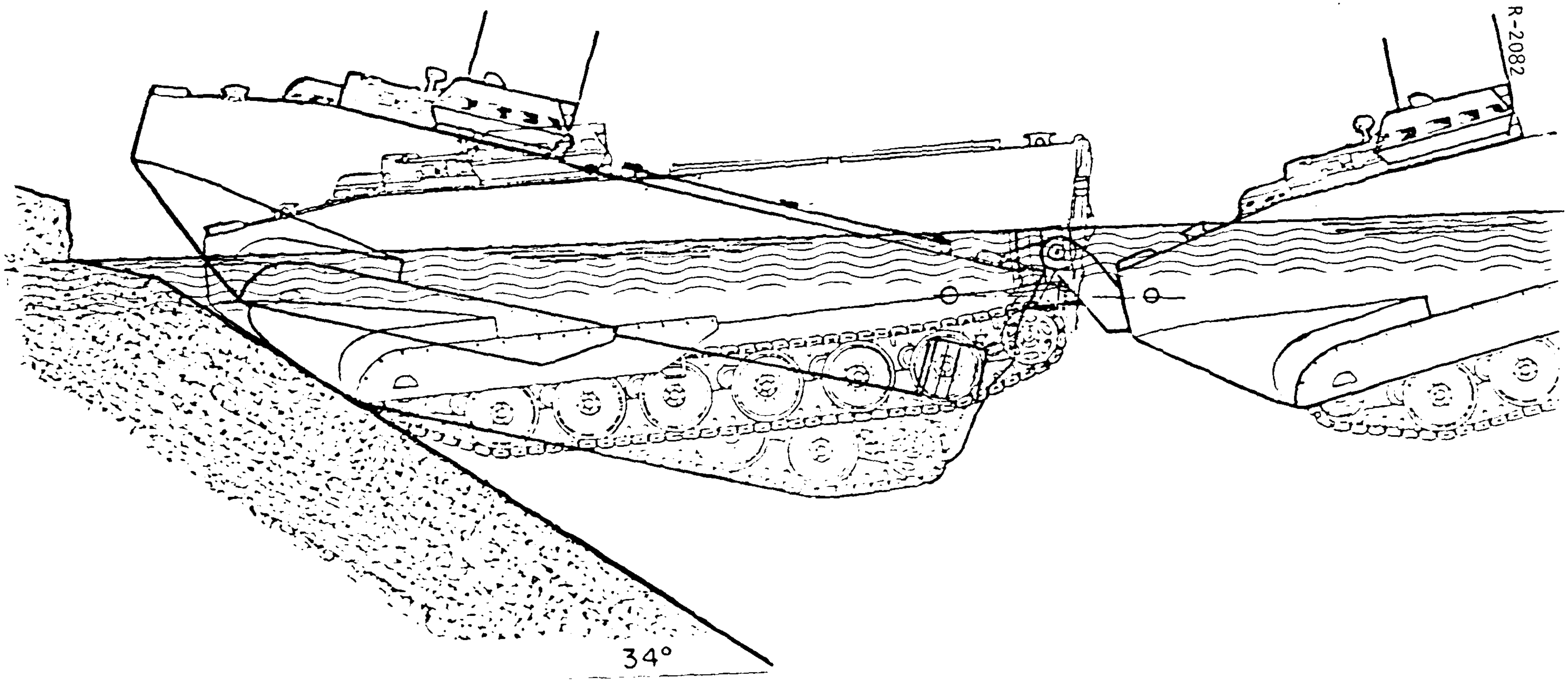
FIGURE ??. Coupled Compared to Single LVT

Davidson Laboratory
Stevens Institute of Technology



WATER EXIT

FIGURE 28. Coupled LVT Compared to Coupled M-113



WATER EXIT

FIGURE 29. Coupled Compared to Single LVT

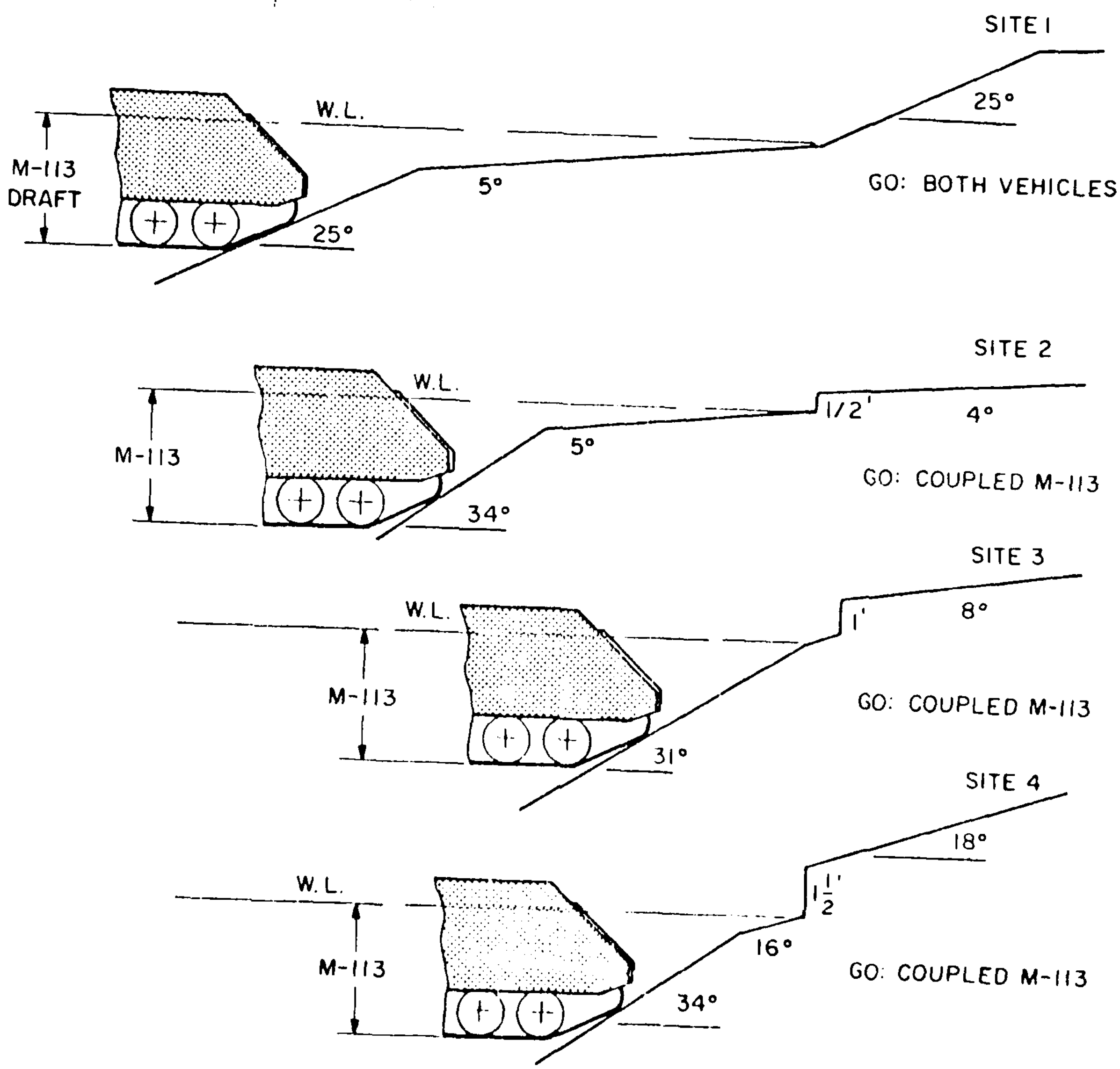


FIGURE 30. Water Exit, Bank Profiles for the CCRV

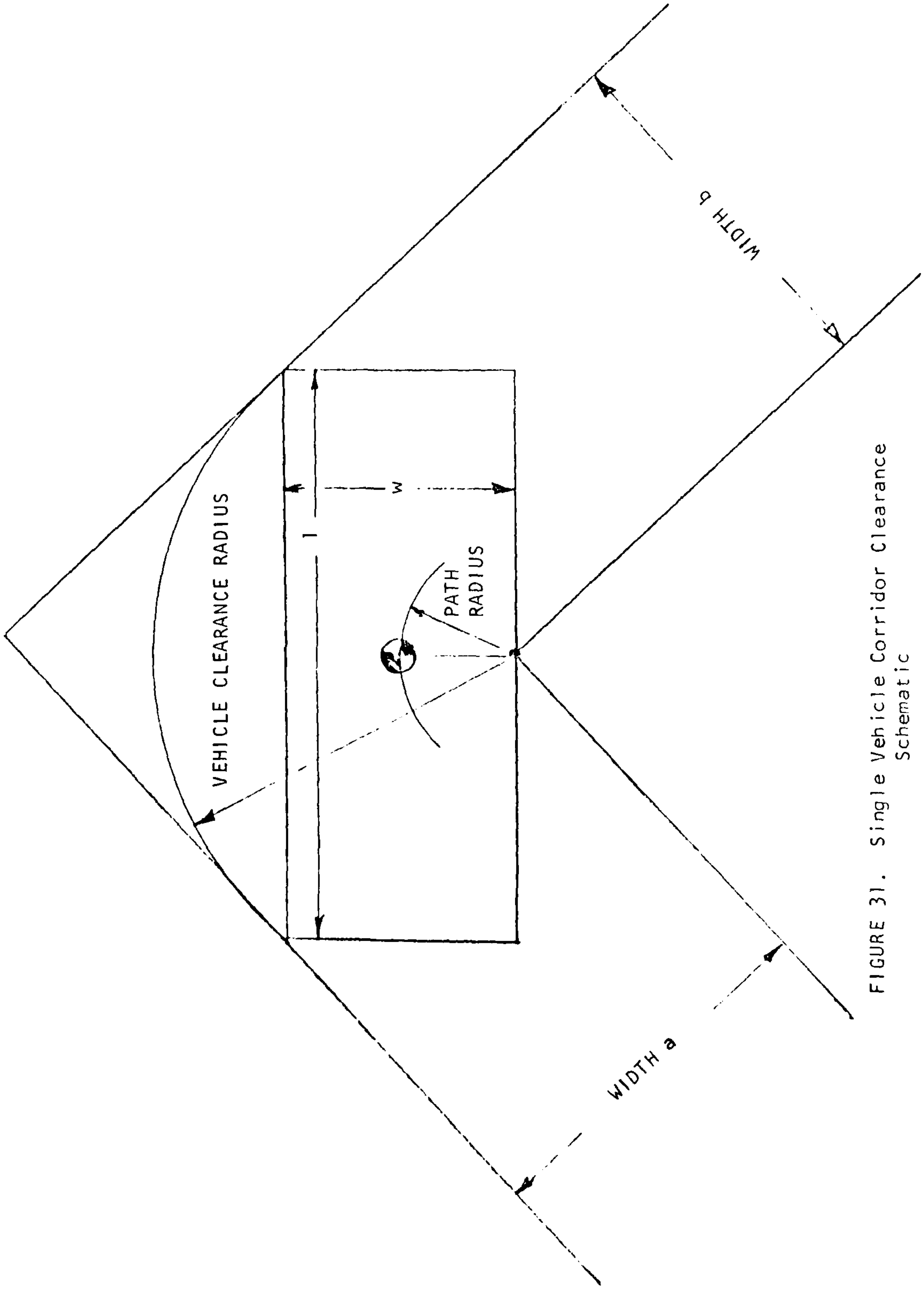


FIGURE 31. Single Vehicle Corridor Clearance Schematic

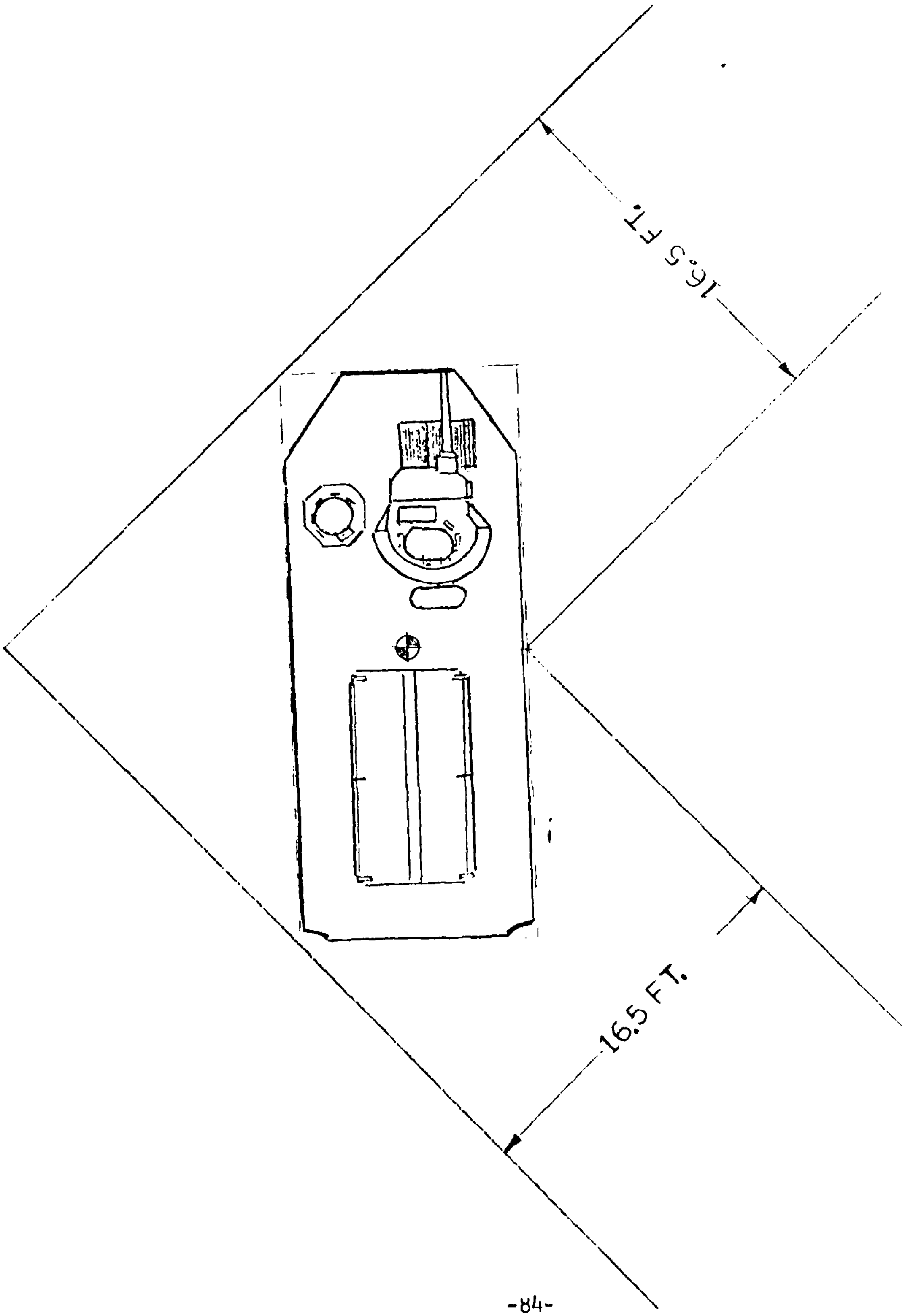


FIGURE 32. Minimum Corridor Width by Geometric Fit, Single Vehicle

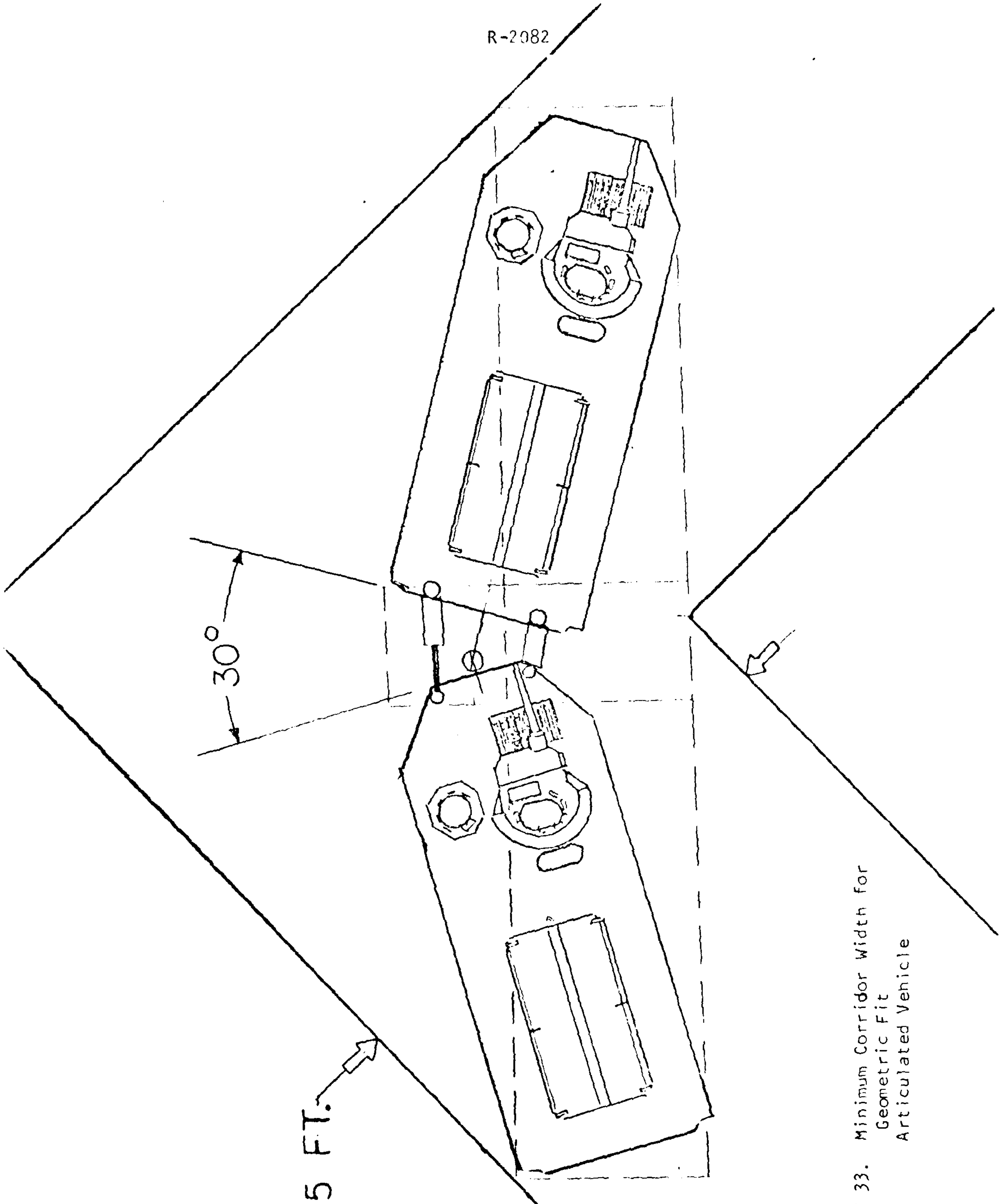


FIGURE 33. Minimum Corridor Width for Geometric Fit Articulated Vehicle

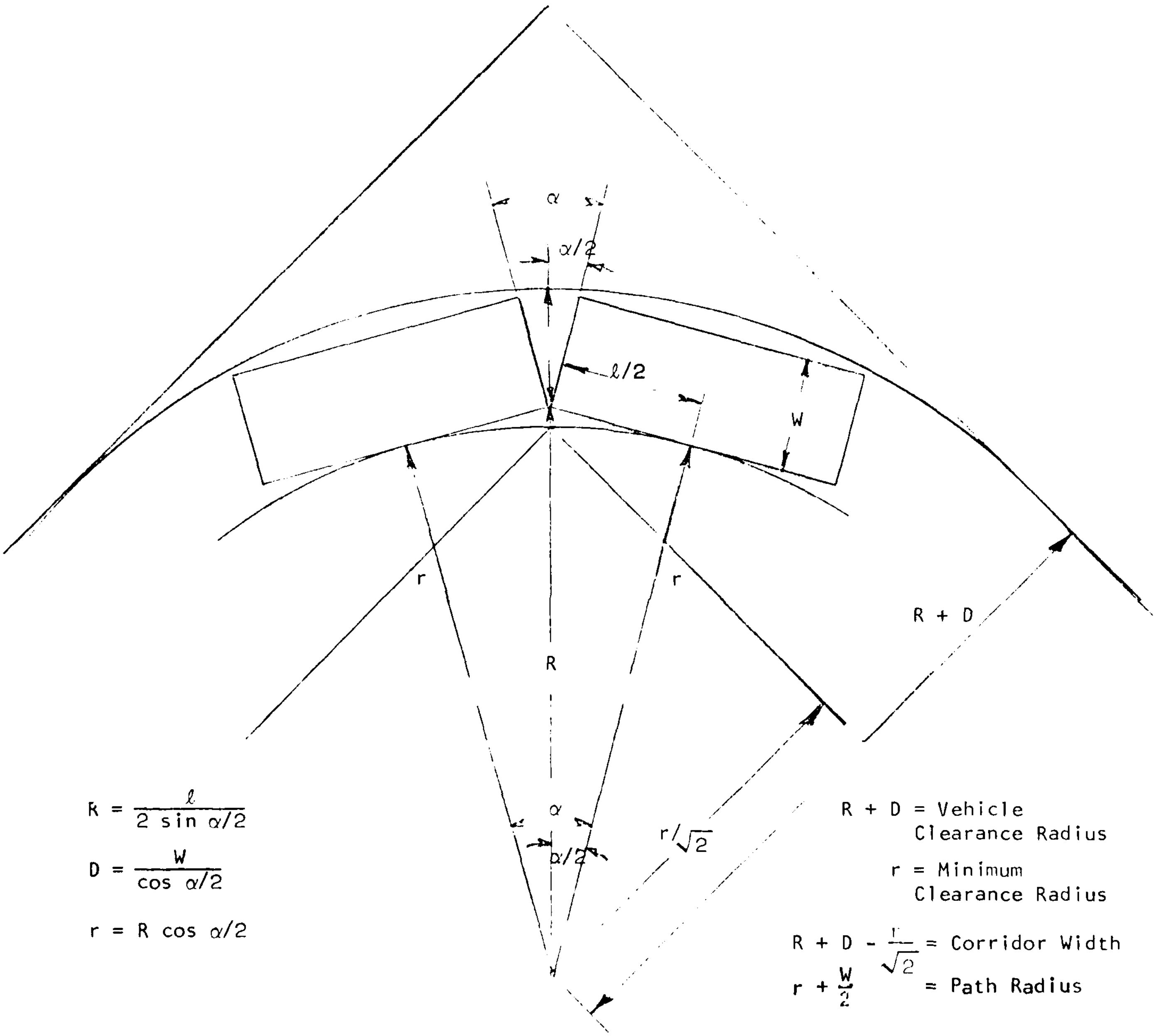
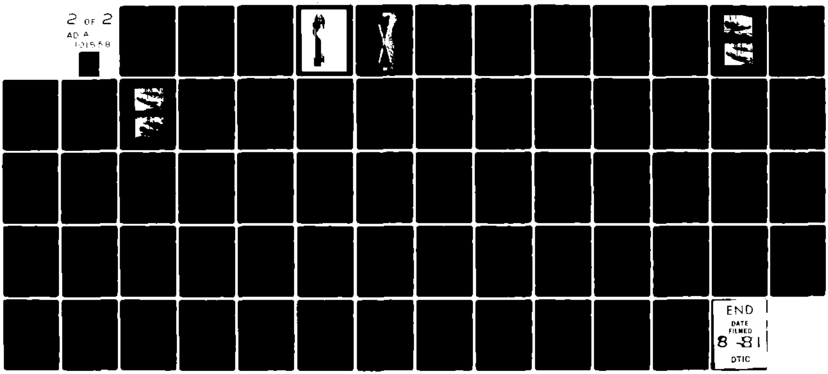


FIGURE 34

Minimum Corridor Width by Articulated Steering

AD-A101 558 STEVENS INST OF TECH HOBOKEN NJ DAVIDSON LAB F/G 19/3
AN EVALUATION OF THE COUPLED LVT CONCEPT.(U)
NOV 79 I O KAMM, P W BROWN, P M BRADY N00014-79-C-0356
UNCLASSIFIED SIT-DL-79-9-2082 NL

AD A
101558



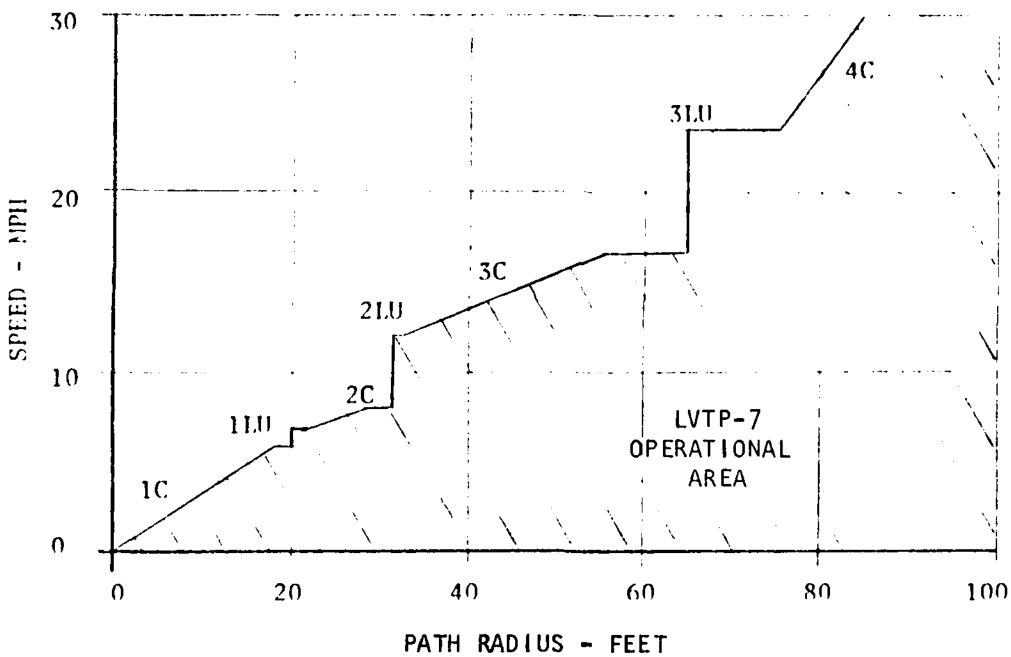


FIGURE 35

Minimum turning radius (to the CG) versus speed for the LVTP7 vehicle with the FMC HS 400 transmission (Note: Converter Lock-up produces constant radius of turn for a given range of speed)

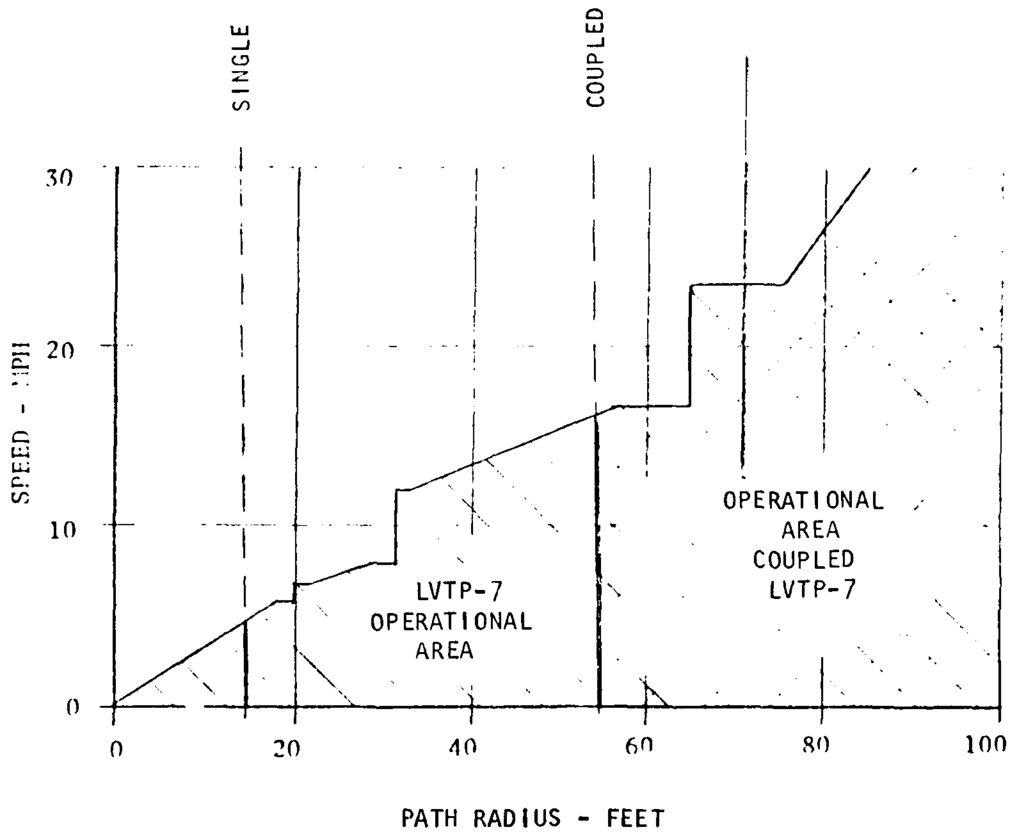


FIGURE 36

Operational Area

LVTP-7 compared to coupled concept

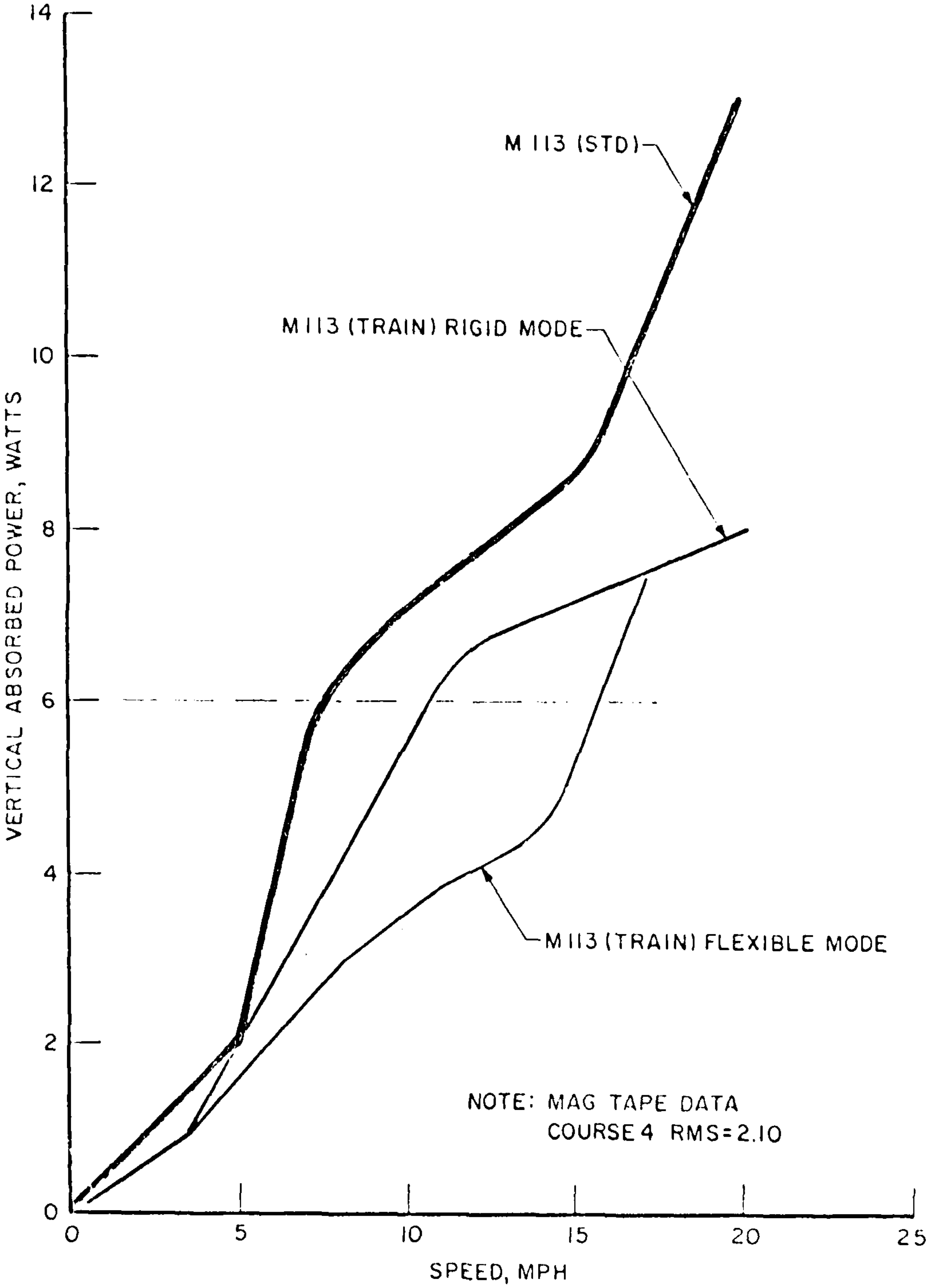


FIGURE 37. ABSORBED POWER VERSUS SPEED
STD M113 & M113 (TRAIN)
HOUGHTON TESTS (SERIES I)

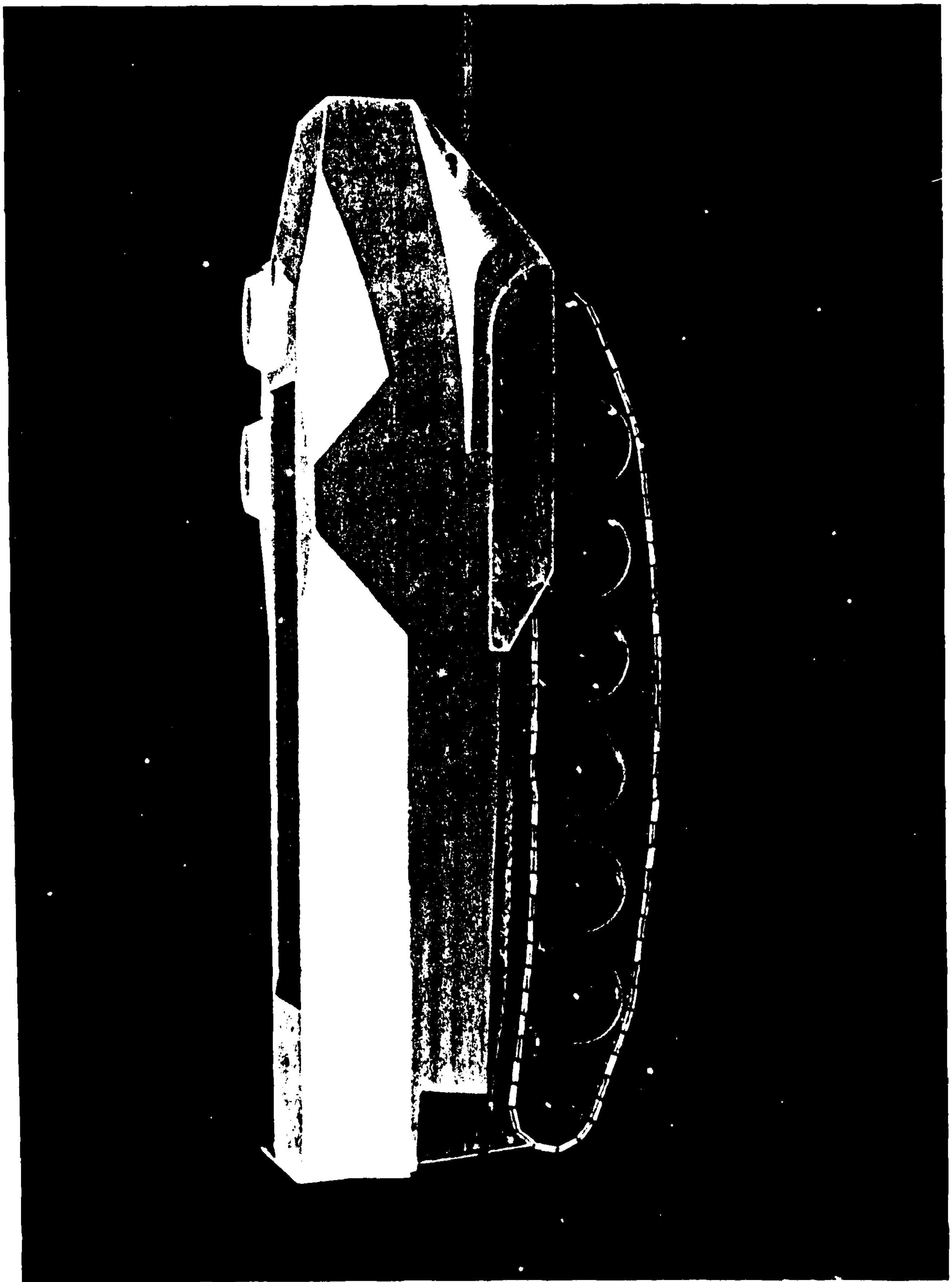


FIGURE 38. 1/8.2 SCALE MODEL LVTP-7

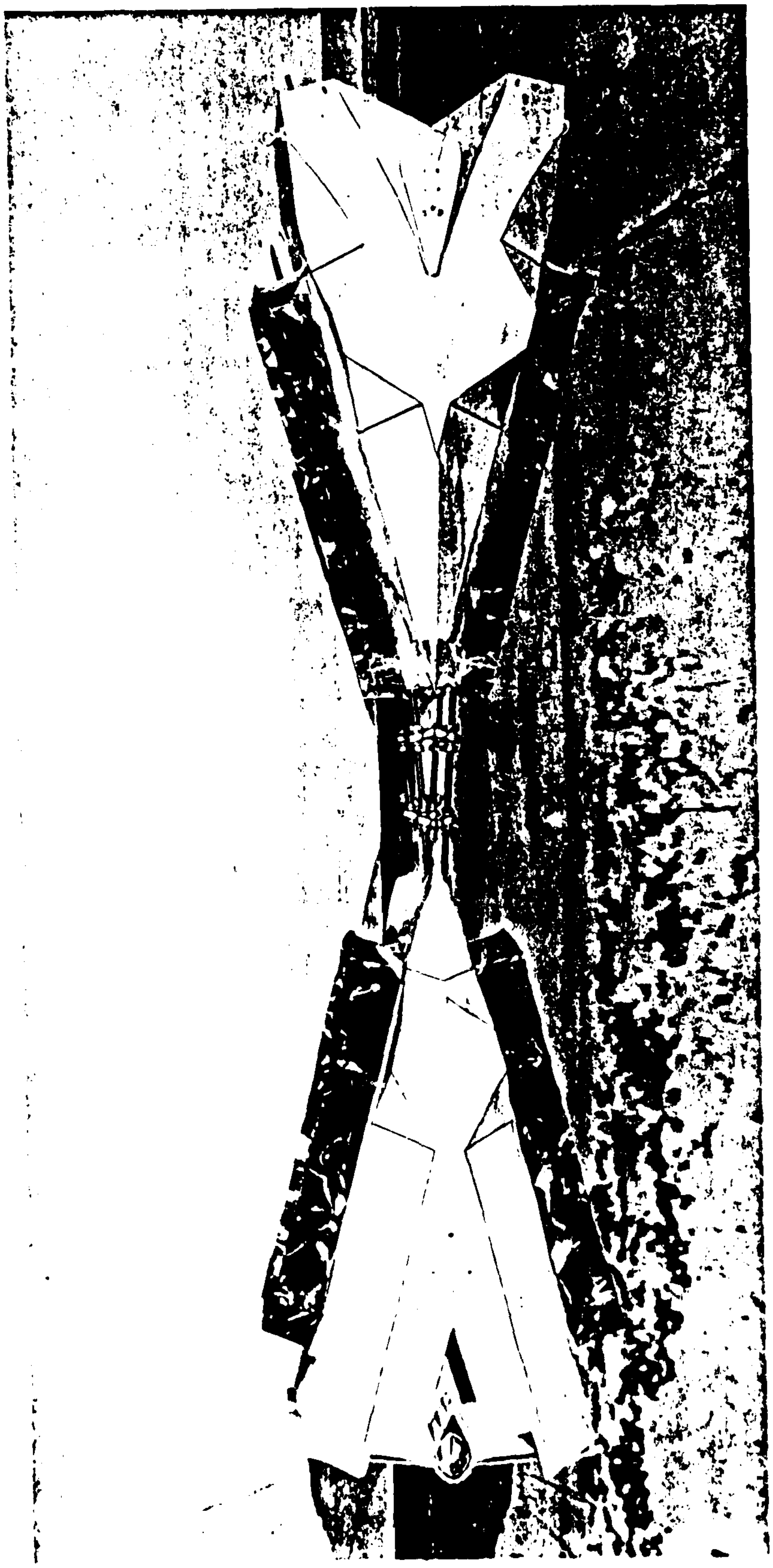


FIGURE 39. COUPLED VEHICLES AT 15° INCIDENCE

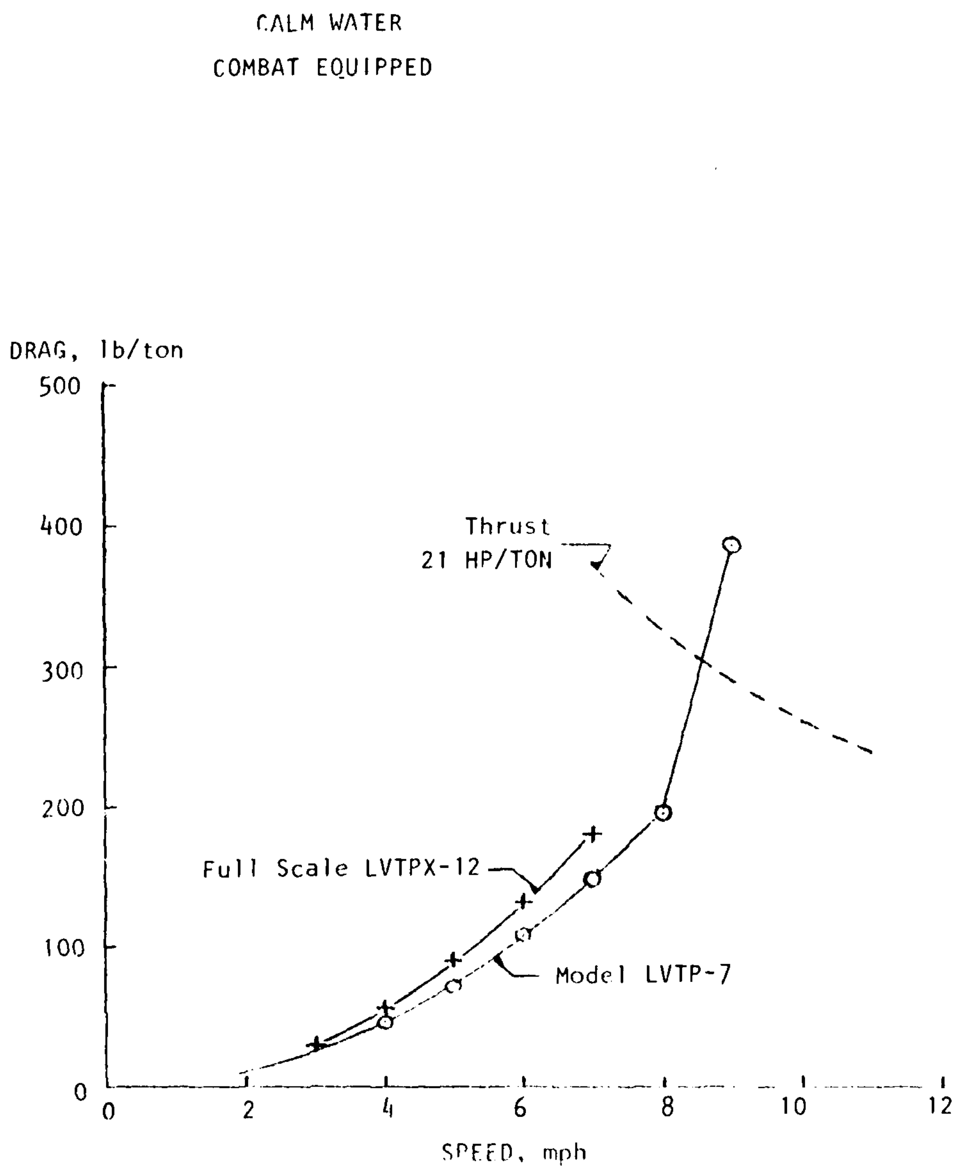


FIGURE 40. SINGLE VEHICLE CALM WATER DRAG COMPARISON

CALM WATER
COMBAT EQUIPPED

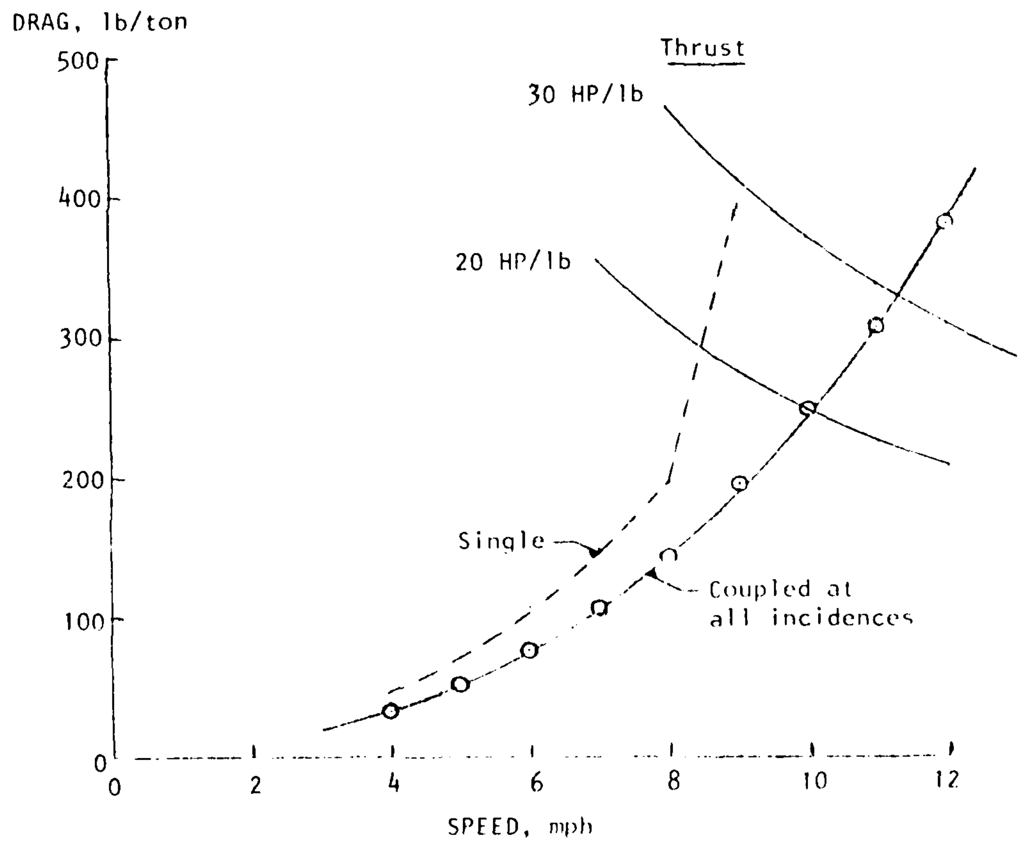


FIGURE 41. CALM WATER DRAG OF COUPLED VEHICLES

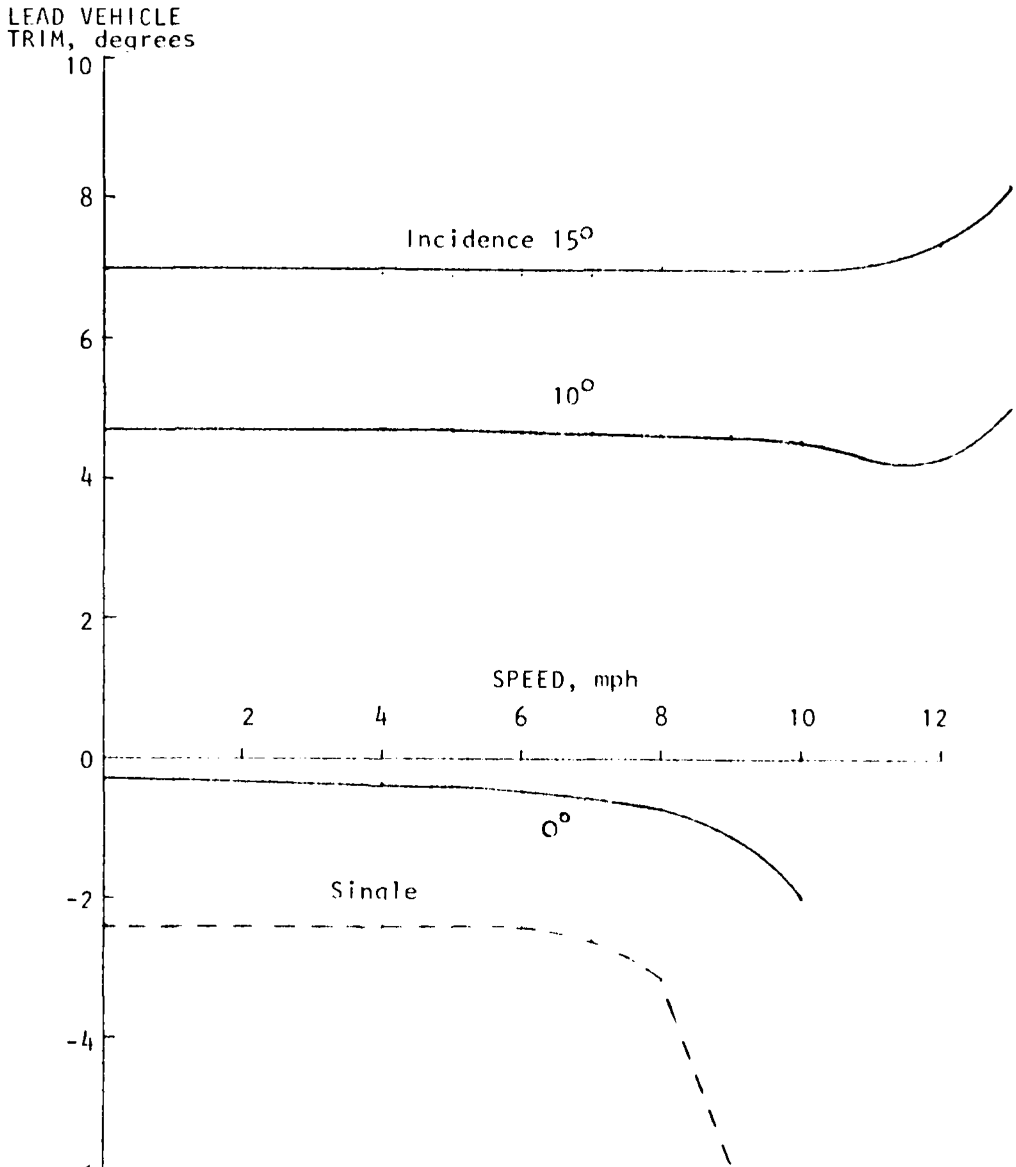


FIGURE 42. TRIM OF COUPLED VEHICLE

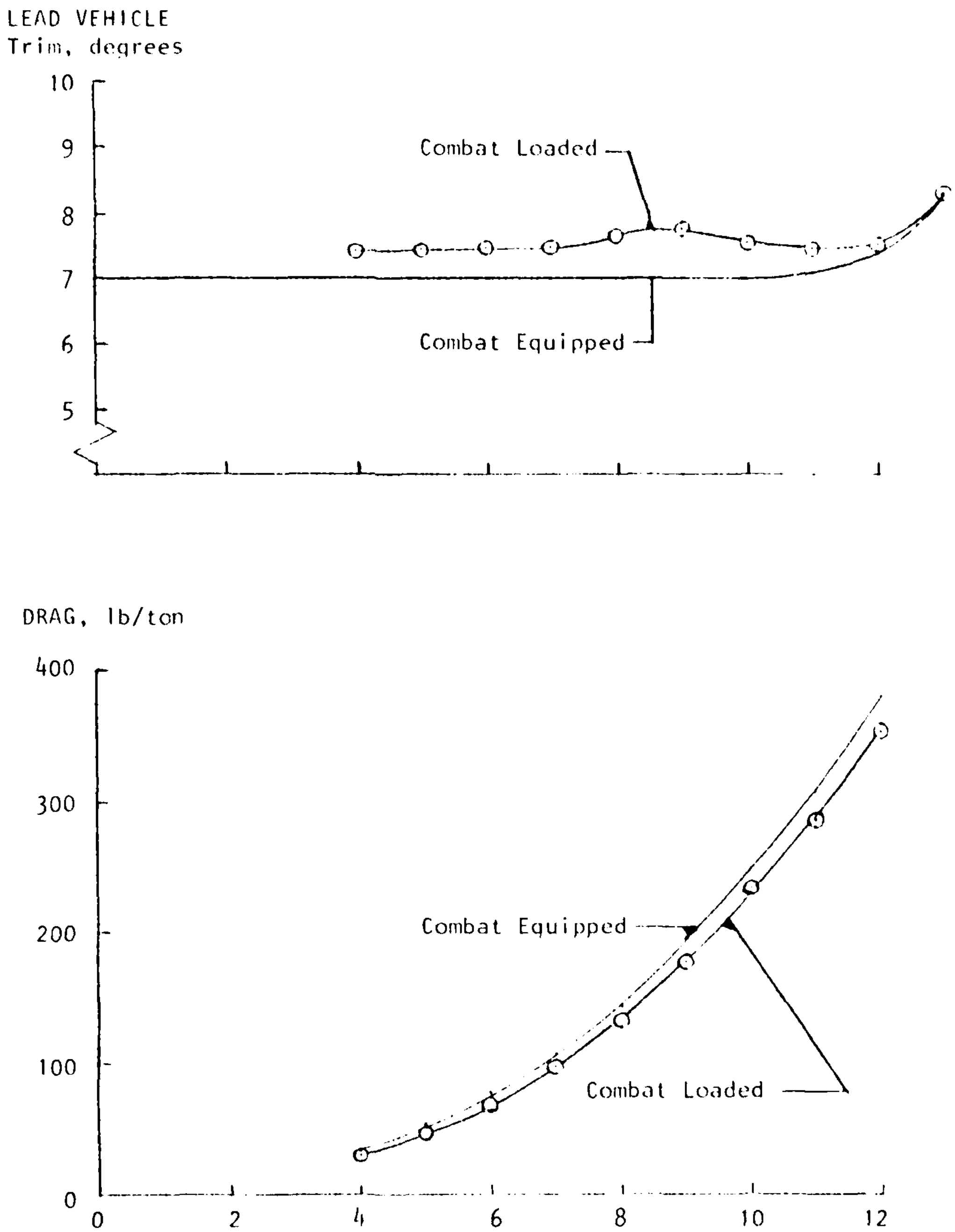


FIGURE 43. EFFECT OF VEHICLE WEIGHT ON CALM WATER DRAG AND TRIM OF COUPLED LVT

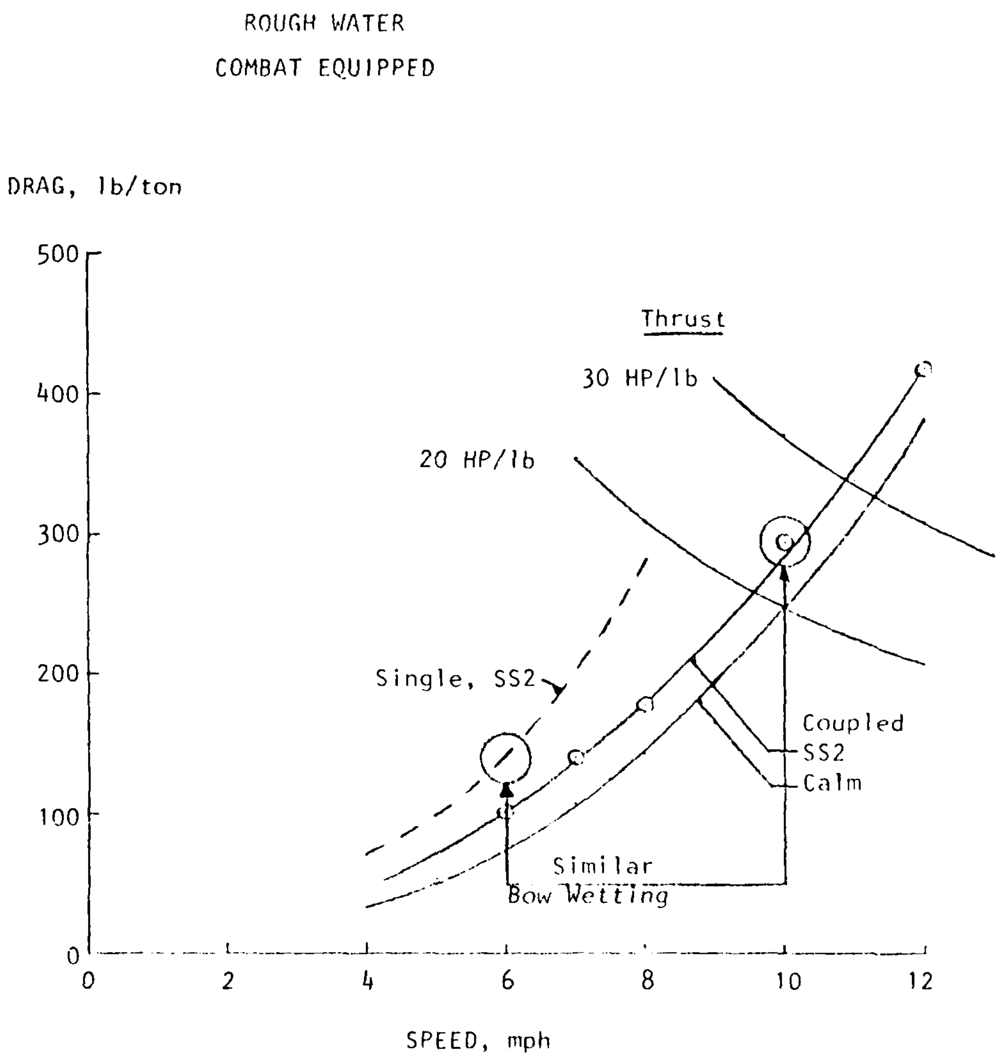
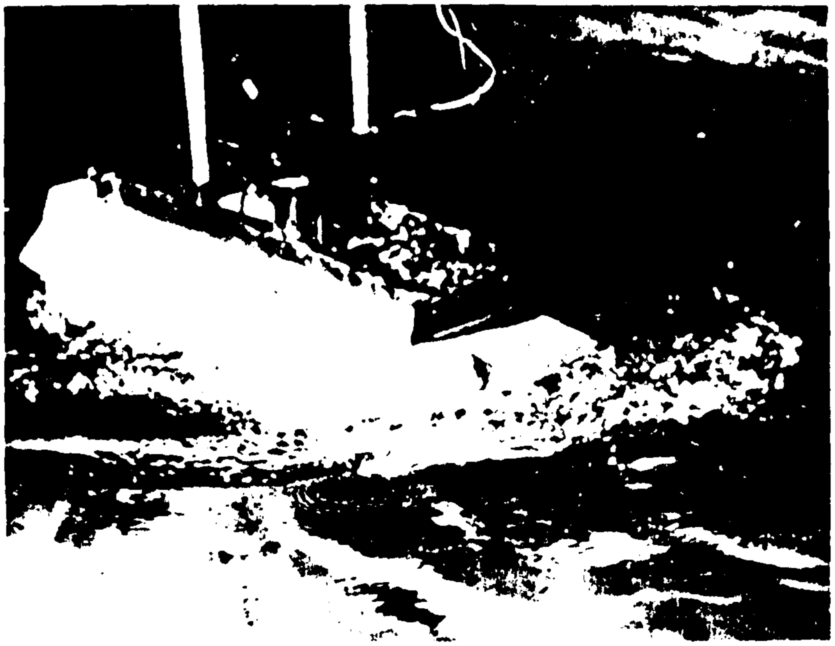
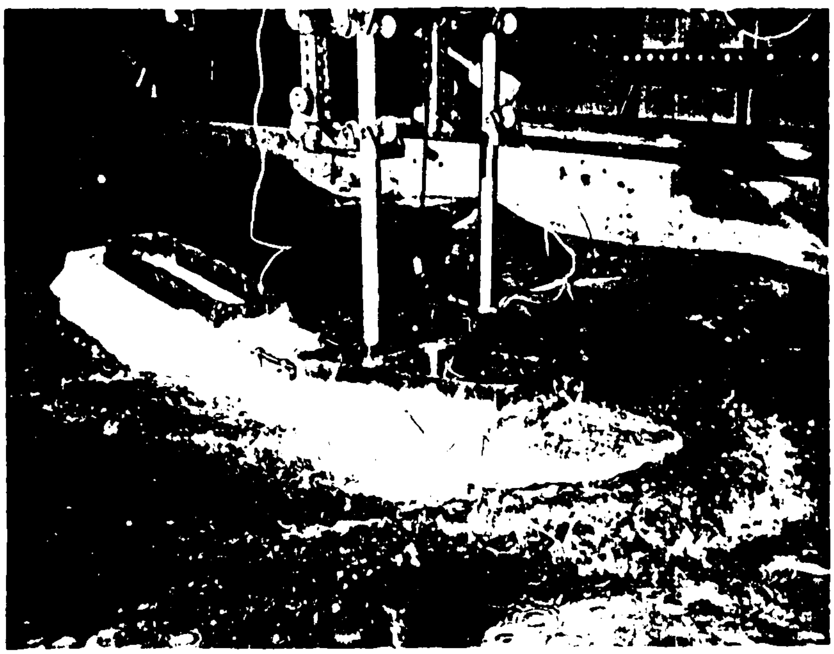


FIGURE 44. PERFORMANCE OF COUPLED LVT IN SEA STATE 2



SINGLE AT 6 MPH



COUPLED AT 10 MPH

FIGURE 45. SINGLE AND COUPLED VEHICLES IN SEA STATE 2

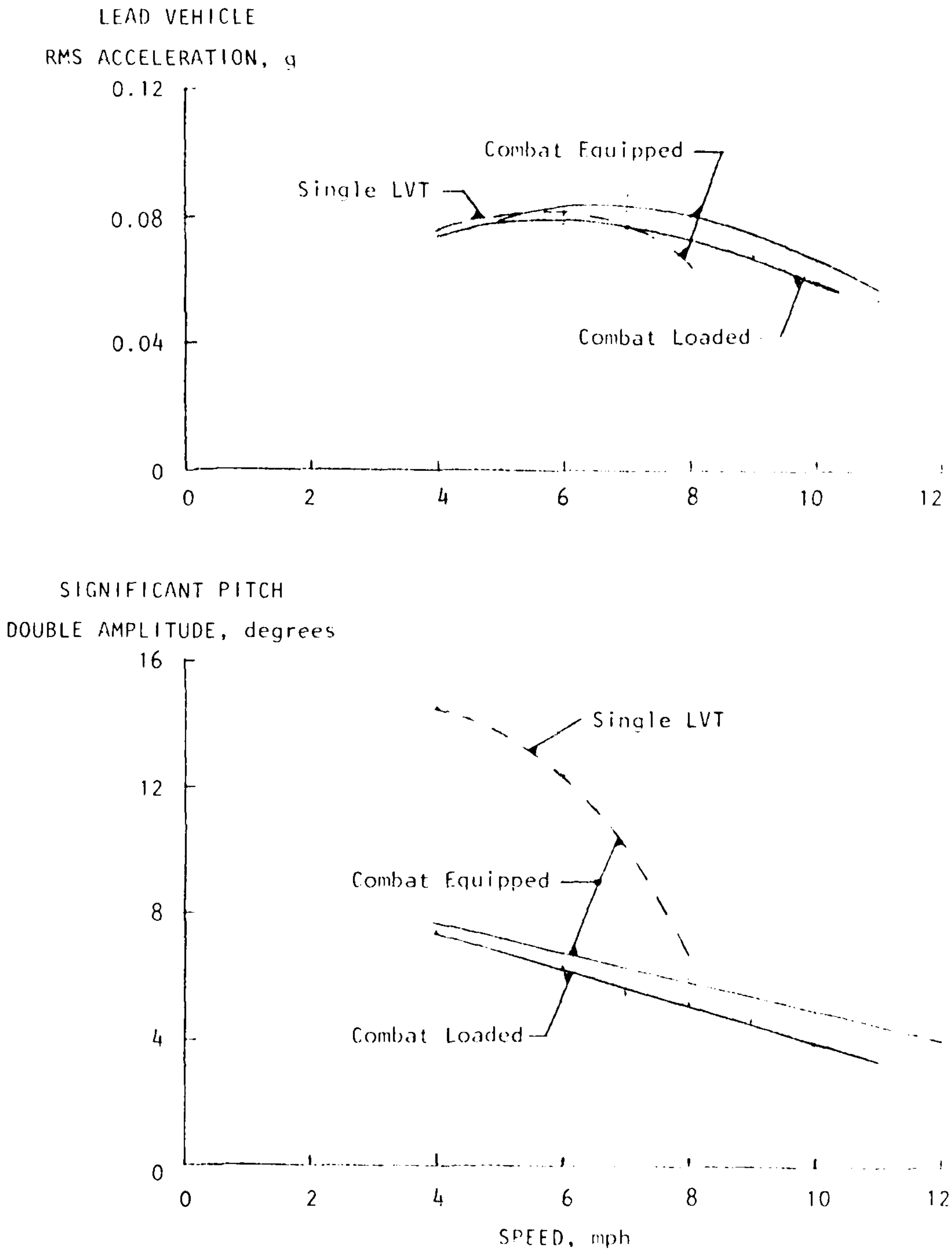


FIGURE 46. SEAKEEPING OF COUPLED LVT IN SEA STATE 2

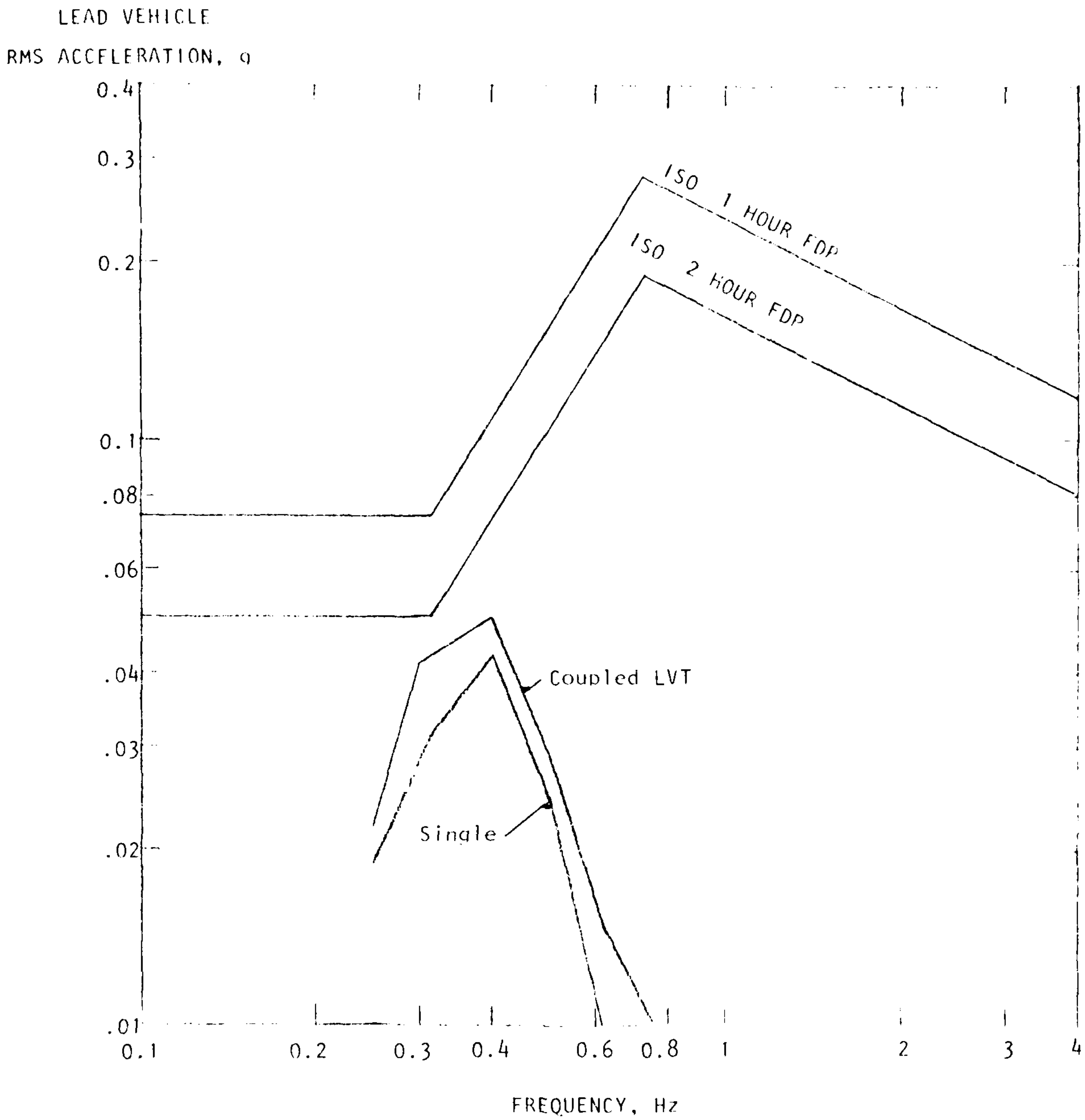


FIGURE 47. RIDE QUALITY IN SEA STATE 2 COMBAT EQUIPPED LOAD AT 8 MPH

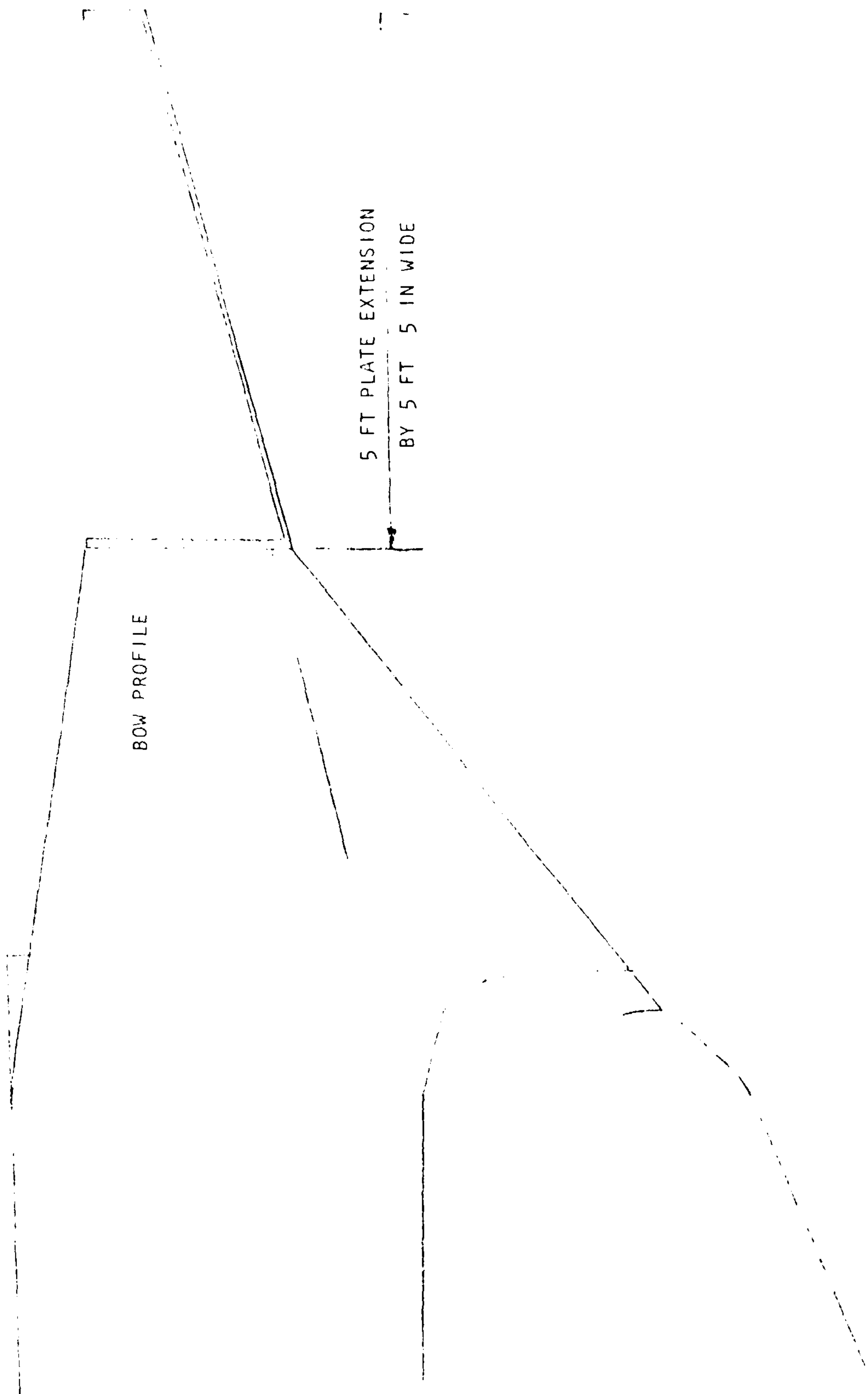
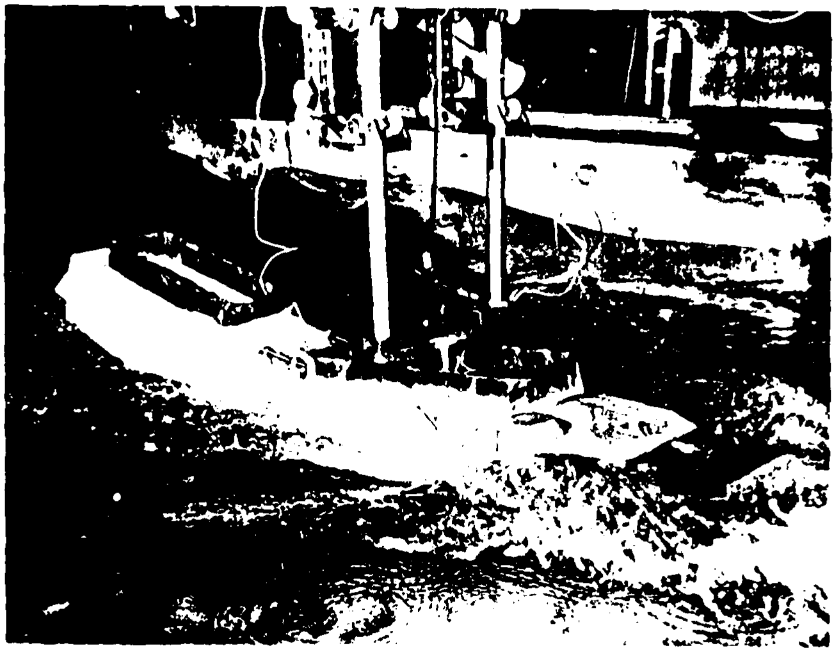


FIGURE 48. BOW EXTENSION



10 MPH

12 MPH

FIGURE 49 COUPLED VEHICLE WITH BOW EXTENSION IN SEA STATE 2

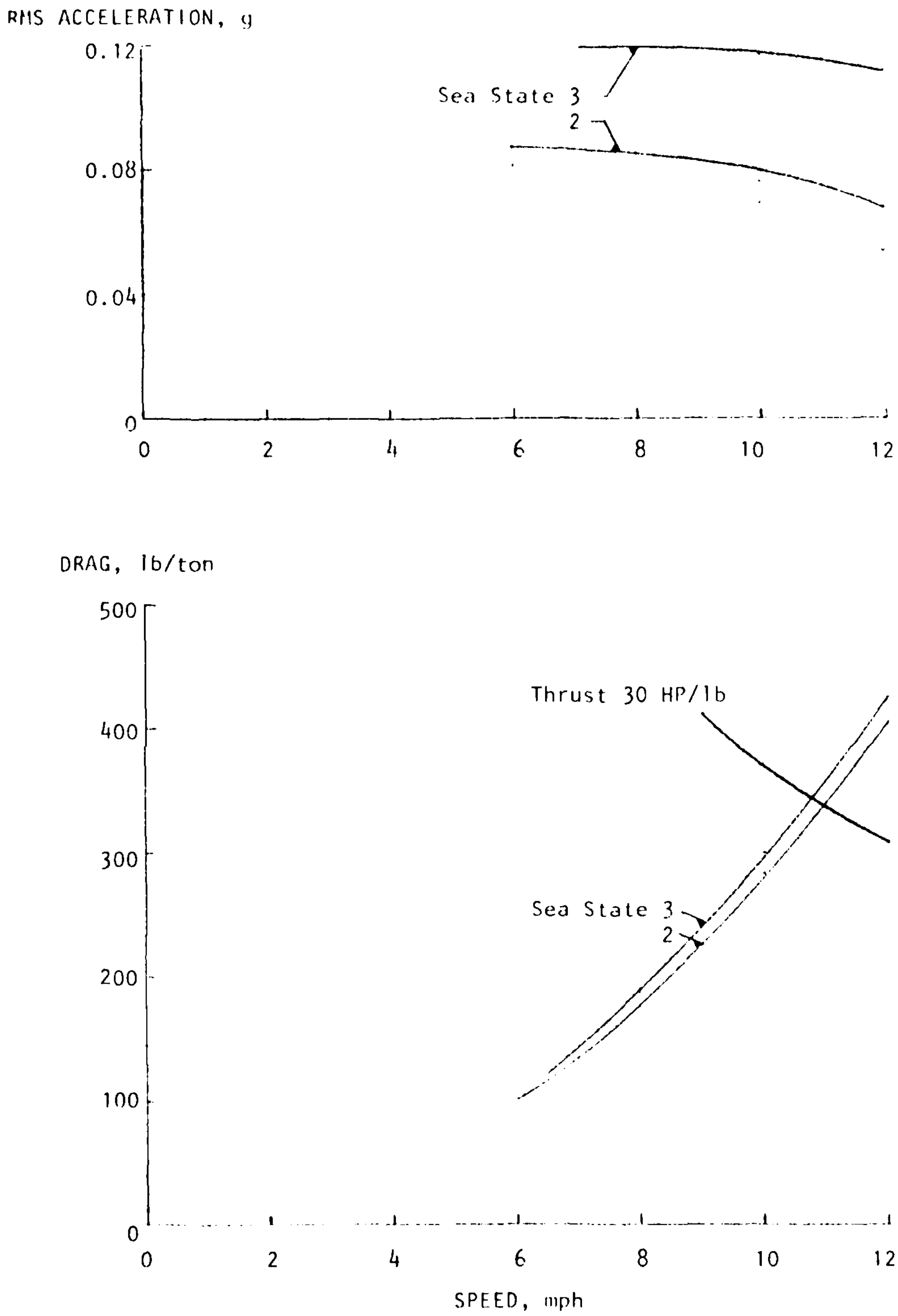


FIGURE 50. SEAKEEPING PERFORMANCE WITH BOW EXTENSION AT COMBAT EQUIPPED LOAD, SEA STATE 2 & 3 COUPLED VEHICLES

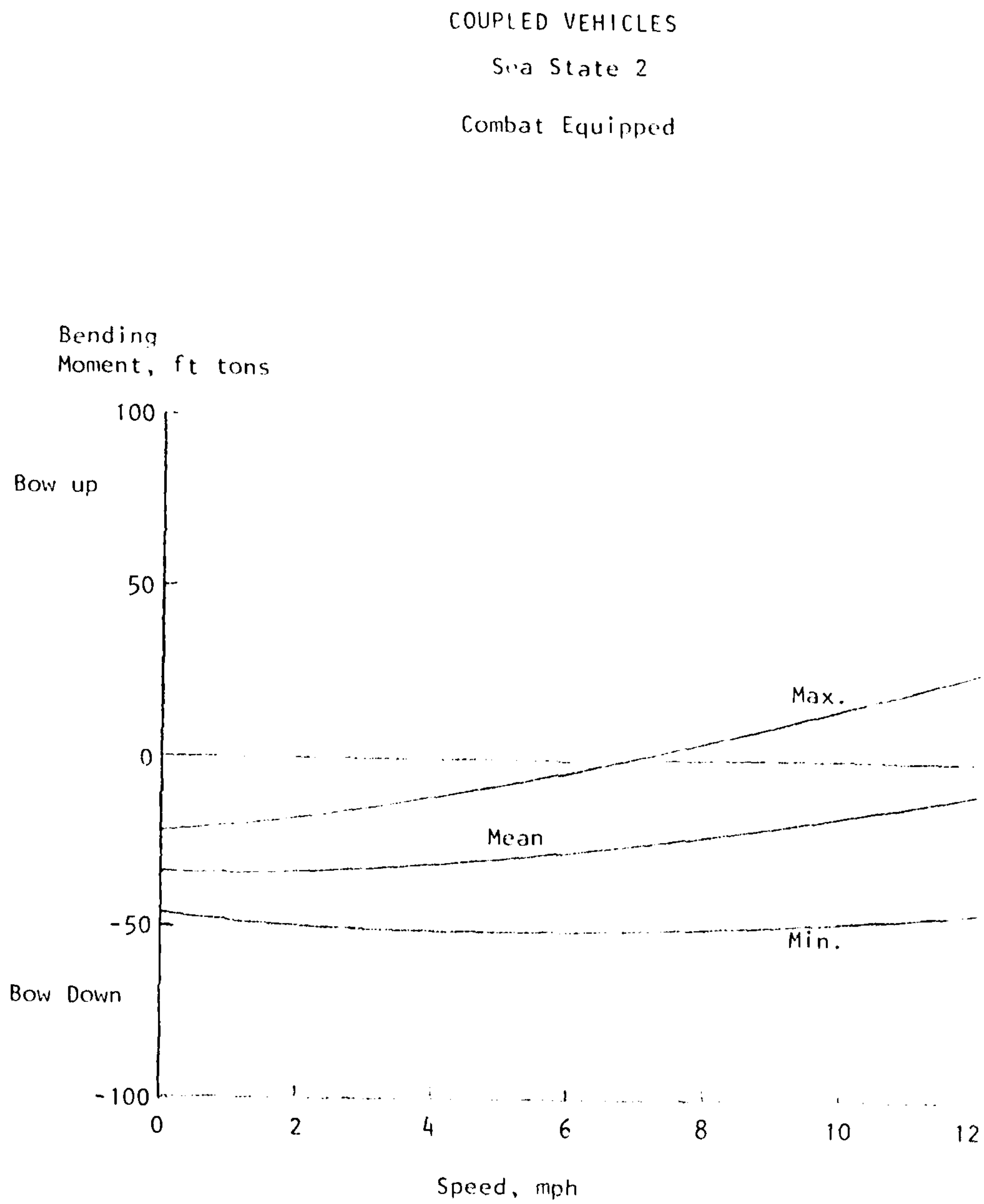


FIGURE 51. BENDING MOMENT BETWEEN VEHICLES IN HEAD SEAS

APPENDIX A

Coupling Joint Calculations

SECTION MODULUS CALCULATION FOR TUBULAR CROSS-SECTION

$$W = \frac{\pi}{32} \quad \frac{D^4 - d^4}{D}$$

FOR: D = 20'' (outside diameter)

d = 19.25'' (inside diameter)

$$W_L = \frac{\pi}{32} \quad \frac{20^4 - 19.25^4}{20.00}$$

$$W_L = 111.35 \text{ in.}^3$$

BENDING MOMENT

FOR LAND M_L = 4,030,000 lbs.in.

FOR WATER M_W = 1,200,000 lbs.in.

STRESS CALCULATION FOR LAND OPERATION

$$\sigma = \frac{M_L}{W_L} = \frac{4,030,000}{111.35} = 36,193.15 \text{ psi}$$

SECTION MODULUS REQUIRED FOR WATER OPERATION

$$W_W = W_L \times \frac{M_W}{M_L} = 111.35 \times \frac{1,200,000}{4,030,000} = 33.16 \text{ in.}^3$$

FOR: 14'' OD - 13.25'' ID Joint

$$W = \frac{\pi}{32} \times \frac{14^4 - 13.25^4}{14} = 53.25 \text{ in.}^3 \text{ available}$$

Calculation of forces in the pitch cylinder

Moment arm L_M = 32" (Distance from the pitch axis to center line of the pitch cylinder, at 0^{o} position).

Force = Moment/L_M

	LAND OPERATION	WATER OPERATION
Moment (lbs.in)	4,020,000	1,200,000
Force Required (lbs.)	125,937	37,500
Section Modulus	111 in^3	53 in^3
Cylinder Size	10" dia. x $4\frac{1}{2}$" rod	7" dia. x 3" rod
FORCES:		
Push (lbs.)	157,000	76,980
Pull (lbs.)	125,000	62,840

PRELIMINARY WEIGHT ESTIMATE

PROTOTYPE VEHICLE COUPLING JOING (AS PER FIGURE 17)

Based on Commercially Available Industrial Components

	LAND OPERATION	WATER OPERATION (ONLY)
MAX. BENDING MOMENT	4,030,000 lb.in.	1,200,000 lbs.in.
COUPLING DEVICE (Joint only)	2,135 lbs. 20" OD cone	1,300 lbs. (est.) 14" OD cone
YAW HYDRAULIC CYLINDER (3,000 psi)	400 lbs. 7" dia., 3" rod, 40" stroke	400 lbs. 7" dia., 3" rod, 40" stroke
PITCH CYLINDER (3,000 psi)	990 lbs. 10" dia., $4\frac{1}{2}$" rod, 40" stroke	400 lbs. 7" dia., 3" rod, 40" stroke
HYDRAULIC PUMP AND CONTROLS	300 lbs.	250 lbs.
TOTAL WEIGHT	3,825 lbs.	2,350 lbs.

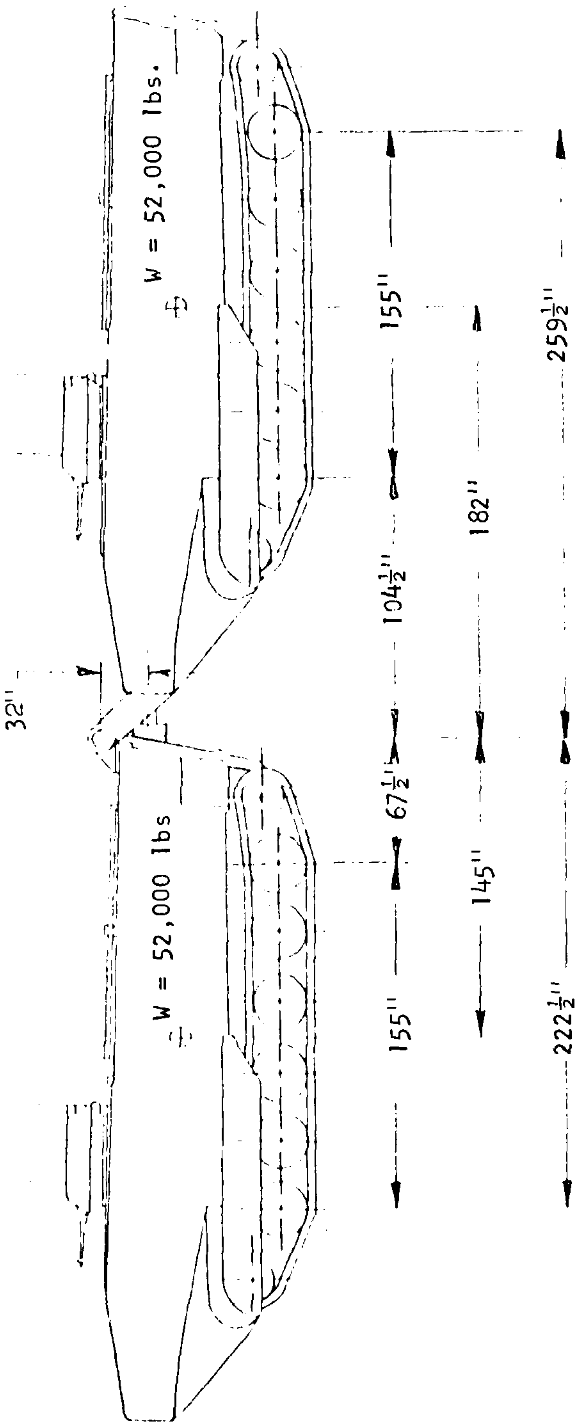


FIGURE A-1

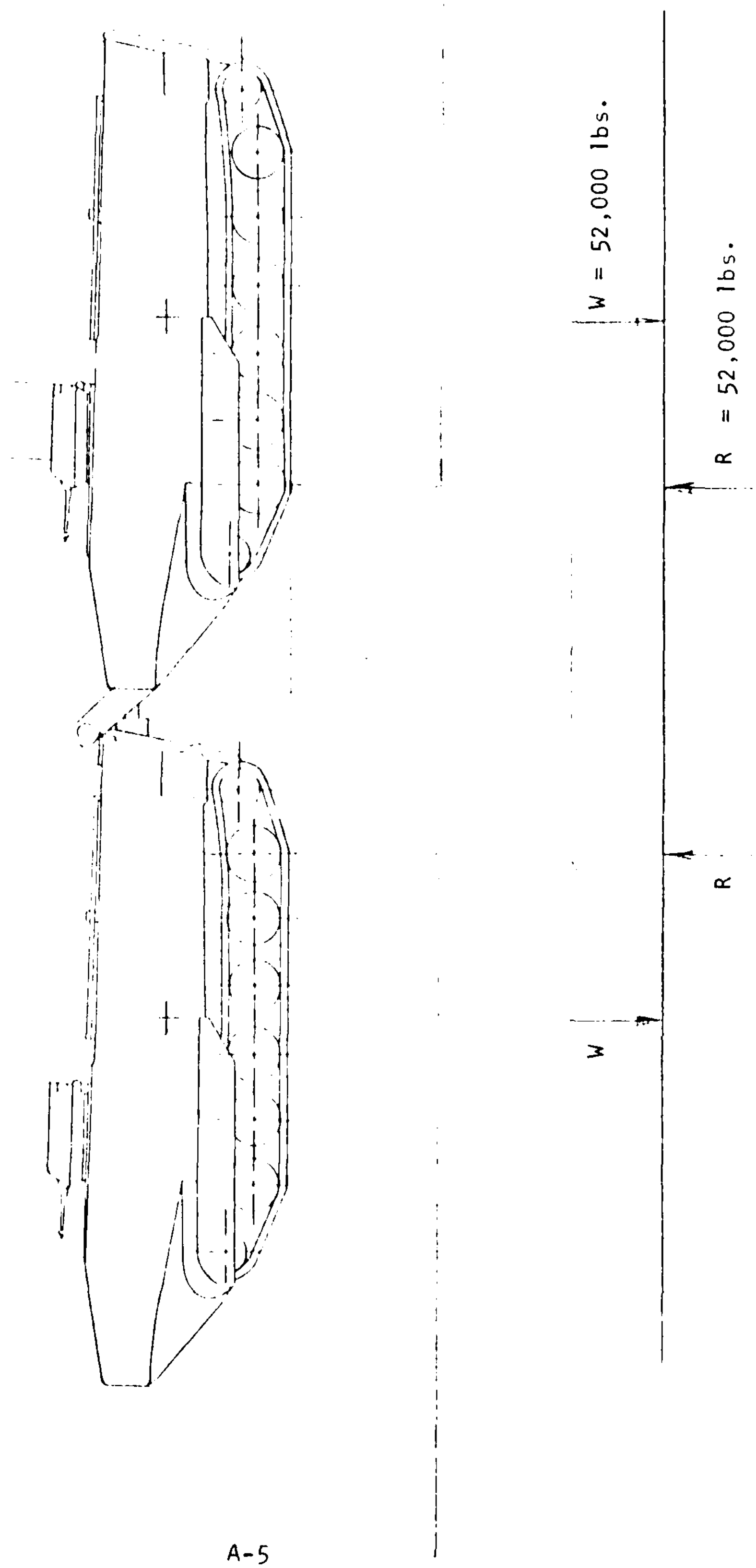


FIGURE A-2

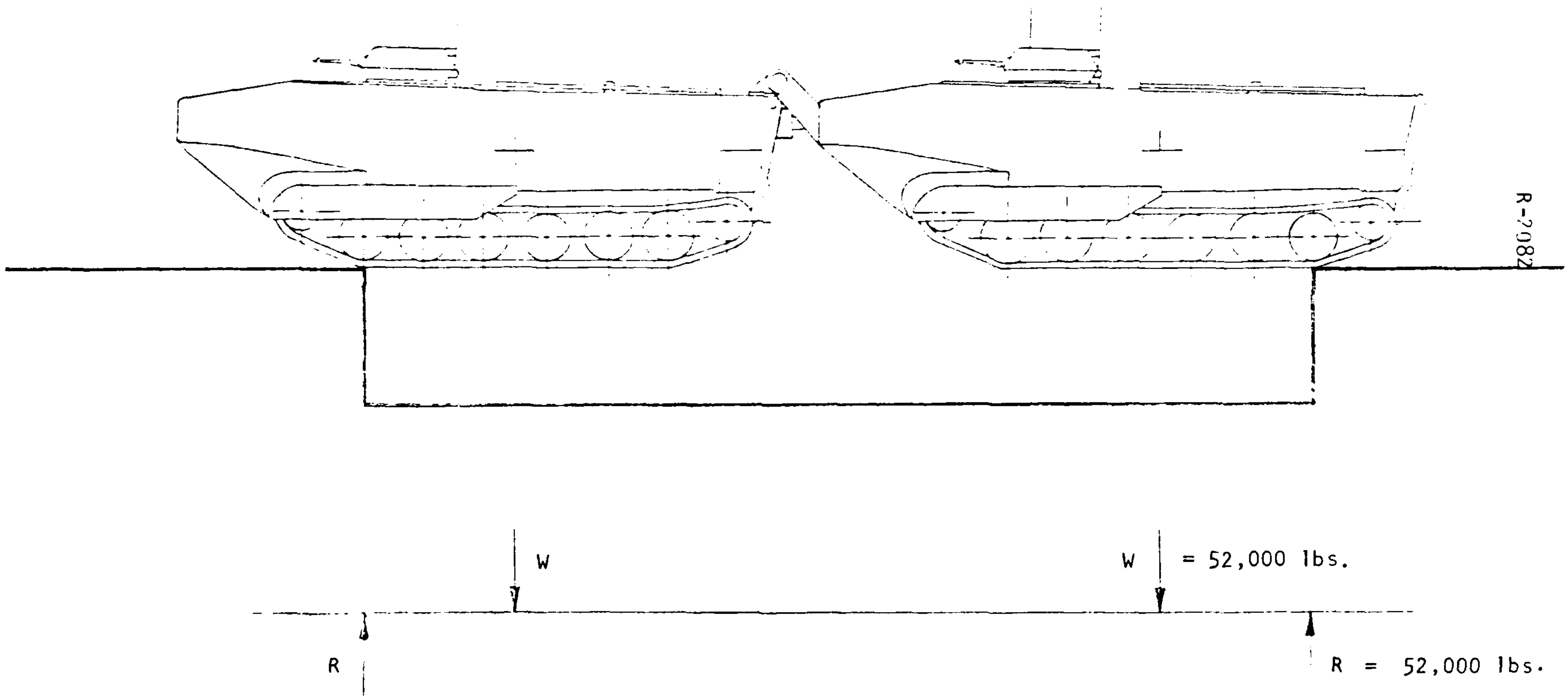


FIGURE A-3

APPENDIX B

ABSTRACTS

Remote Coupling and Manipulation Literature Search

A Compendium of Structural Joints for Assembly. Field and Flight Separation on Missiles

Boeing Co Seattle Wash (059 60)
AUTHOR: Gambrell, R. V.
E08P3B4 Fld: 16D, 13E GRAI7810
2 Jul 68 162p
Rept No: D2-125911-1-Rev-Ltr-B
Monitor: 18
Includes revision letter B dated 10 Dec 68. See also AD-835 942L and AD-840 998L.
Distribution limitation now removed.

Abstract: This report is a Class 2 Research document which contains information to assist the preliminary and conceptual design engineer in selecting a variety of missile joints, including: Payload Stage Assembly and Separation Joints; Booster Stage Assembly and Separation Joints; and Raceway Joints. In addition, information on design considerations and system requirements are included to assist the engineer in making his concept choice and justifying its applicability and feasibility.

Descriptors: (*Joints, *Guided missile components), Separation, Payload, Staging, Launch vehicles, Booster rockets, Bolted joints, Release mechanisms, Adapters, Arming devices, Explosive actuators, Shaped charges, Impact fuzes, Nose cones, Heat shields, Glass textiles, Rocket engine cases, Machining, Seals, Disconnect fittings, Guided missile models, Design, Optimization

Identifiers: Minuteman, Saturn 5, NTISDODXD

AD-845 012/4ST NTIS Prices: PC A08/MF A01

CONNECTOR ALIGNING DEVICE

Patent assigned to Navy
AUTHOR: Damm, Carl A.
021463 Fld: 19A, 13E USGRDR4016
18 May 65
Monitor: 18
Available from Commissioner of Patents, Washington, D.C., 20231, $0.25

Abstract: The weapons stowage, handling, suspension and release system utilizes a coupling system, including a self-aligning device which permits the coupling of two mating units for transferring a bomb or torpedo from one place to another in an aircraft rearming system. The connector aligning device may also be used in helicopter airlift systems. The self-aligning device permits the coupling of two mating units and may be selectively retained on either the male or female portion.

Descriptors: (*Positioning devices(Machinery), Disconnect fittings), (*Disconnect fittings, Positioning devices(Machinery)), Patents, Design, Couplings, Handling, Dollies, Bomb handling vehicles, Bombs, Bomb hoists

Patent 3,183,777

N78 13089*# [illegible]

LASER SPACE RENDEZVOUS AND DOCKING SYSTEM STUDY CONTINUATION Final Report, Feb. 1976 - Jun. 1977

S. Atelman, H. Heynau, S. Levinson and F. Weinding 30 Jun. 1977 70 p

(Contract NAS8-31489)

(NASA-CR-150478; Rept-1257-R-0013) Avail: NTIS HC A04/MF A01 CSCL 22A

Investigations were made of a configuration for a spaceborne laser radar (ladar) to meet the requirements for rendezvous and docking with a cooperative object in synchronous orbit. An analysis was completed of laser phase locking techniques, while experimental verification was made of pulse repetition frequency and resonant scanning control [illegible] measurements on a satellite mock-up were also made. The investigation supports the original contention that a rendezvous and docking ladar can be configured to offer a cost effective and reliable solution to envisioned space missions. Author

N71 22712 [illegible]

THE DYNAMIC RESPONSE OF AXIALLY COUPLED TURBOROTORS

Donald George [illegible] Ph.D. Thesis 1969 124 p

Avail: Univ. Microfilms HC $6.00 Microfilm $3.00 Order No. 70-782[illegible]

An analytical investigation of the effect of coupling characteristics on the response of axially coupled sets of turborotors is presented. A digital computer program based on transfer matrix techniques and utilizing a coupling [illegible] matrix was developed. Gyroscopic effects and both shaft as well as coupling orthotropy were included in the program. [illegible] bearings were assumed and the motion was restricted to [illegible] precession. An illustrative example utilizing two axially coupled modified [illegible] demonstrates that the nature of the coupling has a significant effect on the response characteristics of the rotor set. The coupling must be considered when writing [illegible] specifications and during actual balancing of the rotor set. It is shown that the axial coupling of turborotors can result in the unloading of particular bearings which may initiate [illegible] instabilities that are known to be associated with light loading conditions. Dissert. Abstr.

N71 24897* [illegible] Dallas, Tex.

LATCH EJECTOR UNIT Patent

Stuart K. Elleson, inventor (to NASA) Issued 28 Apr. 1970 (Filed 31 Jul. 1968) 6 p Cl. 294-83; Int. Cl. B64d-11/02 Sponsored by NASA

(NASA-Case-XLA-03538; US-Patent-3,508,779; US-Patent-Appl-SN-749149) Avail: US Patent Office CSCL 13[illegible]

A latching mechanism is described featuring a positive but positively engaged and quick releasing latch [illegible] with a self contained spring [illegible] functions. Official Gazette of the U.S. Patent Office

N75-14820*# Lockheed Missiles and Space Co., Sunnyvale, Calif.

SPACE TUG AUTOMATIC DOCKING CONTROL STUDY Final Report

J. Wohl 31 Oct. 1974 125 p refs

(Contract NAS8-29747)

(NASA-CR-120578; LMSC-D424228) Avail: NTIS HC $5.25 CSCL 22B

A study was conducted to investigate the space tug automatic docking control capabilities. The subjects considered are (1) docking sensor requirements, (2) the influence of the docking mechanism, and (3) the implications and effects of a docking abort. A digital computer simulation was developed which included the primary aspects of the docking maneuver. Author

N70 41808* [illegible]

INDEXED KEYED CONNECTION Patent

[illegible]

[illegible] matching pattern. [illegible]

N72 24686*# Aerojet Nuclear Systems Co., Azusa, Calif.

LONG LIFE SPACE MAINTAINABLE NUCLEAR STAGE REGULATORS AND SHUTOFF VALVES Final Report

Mar. 1972 136 p refs

(Contract NAS8-27568)

(NASA-CR-123568; PN-A-71007) Avail: NTIS HC $14.00 CSCL 18E

The six most promising valve regulator and remote coupling concepts, representing the more radical designs from twenty concepts generated, were investigated. Of the three valves, one has no moving parts because shutoff sealing is accomplished by an electromagnetic field which ionized the flowing fluid. Another valve uses liquid metal to obtain sealing. In the third valve, high sealing forces are generated by heating and expanding trapped hydrogen. The pressure regulator is an electronically controlled, electromechanically operated, single state valve. Its complexity is in electronic circuitry, and the design results in less weight, increased reliability and performance flexibility, and multipurpose application. The two remote couplings feature the minimization of weight and mechanical complexity. One concept uses a low melting temperature metal alloy which is injected into the joint cavity; upon solidification, the alloy provides a seal and a structural joint. The second concept is based on the differential thermal expansion of the coupling mating parts. At thermal equilibrium there is a predetermined interference between the parts, and sealing is achieved by interference loading. Author

N76 14186* National Aeronautics and Space Administration. Lyndon B. Johnson Space Center, Houston, Tex.

SPACECRAFT DOCKING AND ALIGNMENT SYSTEM Patent

Donald C. Cheatham and J. Richard Reed, inventors (to NASA) Issued 7 Oct. 1975 6 p Filed 15 Jun. 1973 Supersedes N73-26879 (11 - 17, p 2086)

(NASA-Case-MSC-12559-1; US-Patent-3,910,533; US-Patent-Appl-SN-370582; US-Patent-Class-244-161; US-Patent-Class-33-286; US-Patent-Class-35-12; US-Patent-Class-178-DIG-20; US-Patent-Class-356-153) Avail: US Patent Office CSCL 22B

A spacecraft docking alignment system is provided utilizing a three dimensional target and screen mounted along the docking axis of one spacecraft and a television camera installed along the docking axis of the other spacecraft. A television display with attendant electronics is provided in the other spacecraft for viewing the relative alignment of the two spacecraft by the astronaut in control of the docking maneuver. Both spacecraft may be equipped with target, screen, camera and display such that either spacecraft may control the docking maneuver.

Official Gazette of the U.S. Patent Office

SIDE PULLAWAY DISCONNECT APPARATUS

Patent assigned to Air Force
AUTHOR: McCulloch, Charles R.
03•4G4 Fld: 13L USGRDR6602
2 Nov 65
Monitor: 18
Available from Commissioner of Patents, Washington, D.C., 20231, $0.50

Abstract: The disconnect apparatus is useful on a rocket sled such as is used to conduct high velocity and high acceleration-deceleration tests of hardware relating to flight. The apparatus disengages one or more quickdisconnect devices from the moving sled transverse to the forward movement of the vehicle. One part of the device is attached to the sled and the other half to the apparatus.

Descriptors: (*Disconnect fittings, Test vehicles), Patents, Rocket-propelled sleds, Hose couplings, Electric connectors, Operation

Patent 3,215,970

Remote Unmanned Work System (RUWS) Matching Latch

Department of the Navy Washington D C (110050)

Patent
AUTHOR: Tryon, Paul V.
D1564H2 Fld: 13J, 47A, 90A GRAI7708
Filed 12 Jan 76, patented 26 Oct 76 6p
Rept No: PAT-APPL-648 220; PATENT-3 987 741
Monitor: 18
Supersedes AD-D002 582.
This Government-owned invention available for U.S. licensing and, possibly, for foreign licensing. Copy of patent available Commissioner of Patents, Washington, D.C. 20231 $0.50.

Abstract: The patent relates to a device whereby a remote interconnection of a first undersea vehicle tethered to a second undersea vehicle is assured by mating assemblies carried on both vehicles. The tethering cable extends through a prod assembly carried on the tethered vehicle and functions mainly to deploy and retrieve the tethered vehicle. During the connection of the two vehicles the cable serves to draw the prod assembly into a latching assembly carried on the second undersea vehicle. Several pawls are cammed into an annular groove on the prod assembly and a pair of opposing helical springs mechanically interact to lock the pawls in place. The coaction of the springs' working on a collar on the prod assembly and a sleeve on the latching assembly makes accidental disengagement nearly impossible until hydraulic actuators assist the force produced by the sleeve spring to overcome the force exerted by the collar spring to release the pawls.

Descriptors: *Underwater vehicles, *Latches, *Patents, Coaxial cables, Mechanical cables, Tethering, Couplings, Release mechanisms, Remote control, Unmanned

Identifiers: PAT-CL-114-16, NTISGPN

AD-D003 298/7ST NTIS Price: Not available NTIS

Coupling Device for Moving Vehicles

National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Md.

Patent Application
AUTHOR: Rudmann, A. A.

E2122H2 Fld: 22B, 22A, 84C, 90A STAR1616
Filed 19 May 78 23p
Rept No: PAT-APPL-907 436; NASA-CASE-GSC-12322-1
Monitor: 18
This Government-owned invention available for U.S. licensing and, possibly, for foreign licensing. Copy of application available NTIS.

Abstract: A mechanical system was designed to capture and/or deploy a device or vehicle having relative motion with respect to another vehicle. The mechanism includes an onboard controlled collapsible iris assembly located at the end of a controlled manipulator system carried by one moving vehicle. The iris assembly by means of the manipulator system encircles a probe located on the other moving vehicle whereupon the iris assembly is activated and one or more iris elements close around the probe, thus capturing and axially aligning the other vehicle with the iris assembly. Additionally, a rotator assembly is included for spinning the iris assembly in a manner adapted to engage the probe of a spinning vehicle.

Descriptors: *Couplings, *Manipulators, *Remote handling, *Rocket vehicles, *Patent applications, *Spacecraft docking, Irises (Mechanical apertures)

Identifiers: NTISNASA

N78-25429/9ST NTIS Prices: PC A02/MF A01

ID NO.- EI71X046979 146979
Automatic coupler for Europe
Ry Gaz v 126 n 17 Sept 4 1970 p 670-1 CODEN: RGZTA
Italian Westinghouse has developed a coupler with automatic air and electric connections which can mate with the Willison or Soviet SA- 3 designs. The air and electric coupling unit described has a pendular suspension support which helps to reduce wear on sliding parts. The stages in the coupling operation are explained.
DESCRIPTORS: (*CARS, *Couplings),
CARD ALERT: 682

ID NO.- EI72X004517 204517
On man- machine coupling concerning the control of a machine whose dynamics do not present damping factors
RAOULT JC; MEZIERE O
Automatic Control in Space, 3, Proc 3rd IFAC Conf Mar 2-6 1970. ISA, 1970 p 35-11
DESCRIPTORS: (*SPACE VEHICLES, *Control), AUTOMATIC CONTROL,
CARD ALERT: 655, 731

ID NO.- EI72X036130 236130
System of driverless power trucks. (Fahrerlose Flurfoerderer fuer unterschiedliche Aufgaben)
Foerdern Heben v 21 n 4 Mar 1971 p 206-8
This article deals with the development and present state of engineering of a driverless power truck system, using sit-on tractors, fork lift trucks and in-floor tractors which are capable of reversing. Automatic coupling and decoupling on the tractor and pallet pickup and depositing on the fork lift truck are possible. In German with English abstract

DESCRIPTORS: (*INDUSTRIAL TRUCKS, *Control), (TRACTORS, Remote Control),
CARD ALERT: 663, 691, 731

N78 19036*# Martin Marietta Corp Denver, Colo
DOCKING AND RETRIEVAL MECHANISM c18
J Robert Tewell and Richard A Spencer *In* NASA Goddard Res Center The 11th Aerospace Mech Symp Apr 1977 p 101 110 refs (For availability see N78-19026 09-99)
(Contract NAS8-31290)
Avail NTIS HC A11/MF A01 CSCL 22B

An engineering prototype docking and retrieval mechanism (DRM) which enables two spacecraft to dock and be structurally joined on orbit is described. The joining of two spacecraft or payloads on orbit supports future planned space activities such as payload servicing, deployment and retrieval, and assembly of large space systems. Advantages of the DRM include: it is a nonimpact docking mechanism, does not require impact absorbing mechanisms or attitude stabilization on the target spacecraft, is capable of docking to a spinning spacecraft, and can spin up and deploy a spinning spacecraft or payload. Author

N76 21245*# Martin Marietta Corp Denver Colo
SPACE TUG DOCKING STUDY VOLUME 1. EXECUTIVE SUMMARY Final Report
Mar 1976 49 p 5 Vol
(Contract NAS8-31542)
(NASA-CR-144239 MCR-76-3-Vol-1) Avail NTIS HC $4.00 CSCL 22B

Results of a detailed systems analysis of the entire rendezvous and docking operation to be performed by the all up space tug are presented. Specific areas investigated include: generating of operational requirements and a data base of candidate operational techniques and subsystem mechanizations, selection and ranking of integrated system designs capable of meeting the requirements generated, and definition of the simulation demonstration program required to select and prove the most effective manual, autonomous, and hybrid rendezvous and docking systems. J M S

DUCT COUPLING FOR SINGLE HANDED OPERATION Patent
William N. Myers, inventor (to NASA) Issued 8 Dec. 1970 Filed 5 Jun. 1969 5 p Cl 285-38 Cl 285-317 Cl 285-314 Cl 285-406 Int Cl F16l-37/10
(NASA-Case-MFS-20395 US-Patent-3 545 792
US Patent Appl SN 830715) Avail US Patent Office CSCL 13I

A quick disconnect duct coupling device is described which may be operated with the use of one hand in a zero gravity environment. A first duct section carries spring urged latches that engage a second duct section. The latches are spring biased toward the locking position and are moved to the unlocking position by the rotation of a ring mounted on the first duct section. The ring is rotated by manipulation of a handle that is associated with the ring and the first duct section.

Official Gazette of the U.S. Patent Office

N71-10782* National Aeronautics and Space Administration John F. Kennedy Space Center, Cocoa Beach, Fla.
QUICK ATTACH AND RELEASE FLUID COUPLING ASSEMBLY Patent
Curt P. Herold and Sam D. Stanley, inventors (to NASA) Issued 16 May 1967 (Filed 3 Apr. 1964) 10 p Cl 285-24
(NASA-Case-XKS-01985; US-Patent-3 319 979;
US Patent Appl SN 357337) Avail US Patent Office CSCL 13I

A quick release coupling for [illegible] with a cryogenic propellant system [illegible] sealing surfaces, one in the form of a sphere [illegible] other conical in shape. The design of the coupling [illegible] leakproof joint under [illegible] changes, severe vibrations, rapid flow and pressure changes [illegible] various degrees of material contraction and flexing caused by extreme temperature variations during fueling. A knife edged annual gasket is located between the two surfaces for eliminating leaks and [illegible] the surfaces together. A pressure operated mechanism increases the seating pressure of the seal as fluid flows through the coupling. R B

N70 41679* National Aeronautics and Space Administration Langley Research Center, Langley Station, Va.
QUICK RELEASE SEPARATION MECHANISM Patent
William E. Newcomb, inventor (to NASA) Issued 7 Feb. 1967 (Filed 23 Dec. 1965) 7 p Cl 102-49
(NASA-Case-XLA-01441; US-Patent-3 302
US Patent Appl SN 516161) Avail US Patent Office CSCL [illegible]

A mechanism is described which [illegible] the stages of an aerospace vehicle [illegible] uniform separation at a predetermined [illegible] operate with [illegible] which permits [illegible] compressed spring. The [illegible] permits utilization of the [illegible] redundancy may be provided [illegible] elements and springs. [illegible] well as space debris [illegible] as the parts remain attached to parent structures. F A B

Automatic Remote Control Coupler for Mine Cars

Foster-Miller Associates, Inc., Waltham, Mass.*Bureau of Mines, Washington, D.C. (142 400)

Final rept. 14 Jun 74-16 Apr 76
AUTHOR: Atkinson, Dick T.; Aponick, Anthony A. Jr; Lane, Alan J.; Lombardi, Anthony J.
D2371L4 Fld: 81, 43A GRAI7713
16 Apr 76 139p
Contract: H0346042
Monitor: BuMines-OFR 67-77

Abstract: This report describes the Foster-Miller program that designed, developed, built, and tested an automatic, remote control mine car coupler. This new coupler gives the motorman the capability to selectively couple and uncouple cars from the locomotive, to transmit braking intelligence to the coupled cars, and to determine if the trip is intact. Hazards due to derailment and runaway cars will be reduced as the brakes are automatically applied in any uncoupled car. Laboratory tests described herein have been completed on the coupler set. Applications include, but are not limited to, the unit train system.

Descriptors: *Coal mining, *Mine cars, *Remote control, *Couplings, Mine haulage, Automatic control equipment, Braking

Identifiers: NTISDIBM

PB-265 558/7ST NTIS Prices: PC A07/MF A01

APPENDIX C

ACCELERATION CURVES

Various Coupled Vehicles and Rolling Resistances

The upper curve represents the performance with both vehicles powered. The lower curve represents the performance with one engine disabled.

Figure C-1 through C-10	Coupled M113-A1
Figure C-11 through C-20	Coupled LVTP-7
Figure C-21 through C-30	Coupled LVT-X

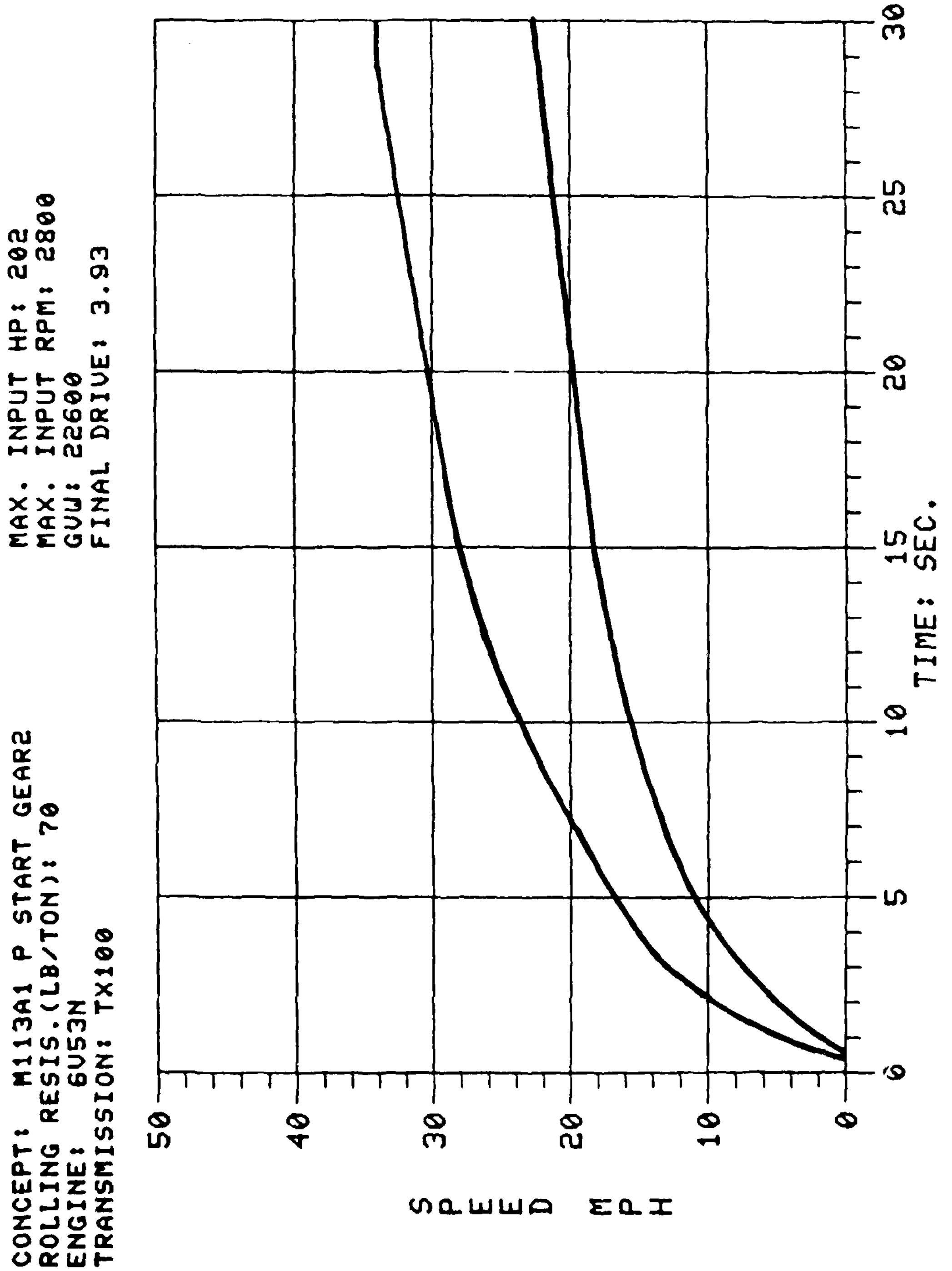

CONCEPT: M113A1 P START GEAR2
ROLLING RESIS.(LB/TON): 70
ENGINE: 6V53N
TRANSMISSION: TX100
MAX. INPUT HP: 202
MAX. INPUT RPM: 2800
GVW: 22600
FINAL DRIVE: 3.93
SPEED MPH
0
10
20
30
40
50
TIME: SEC.
0
5
10
15
20
25
30

FIGURE C-1

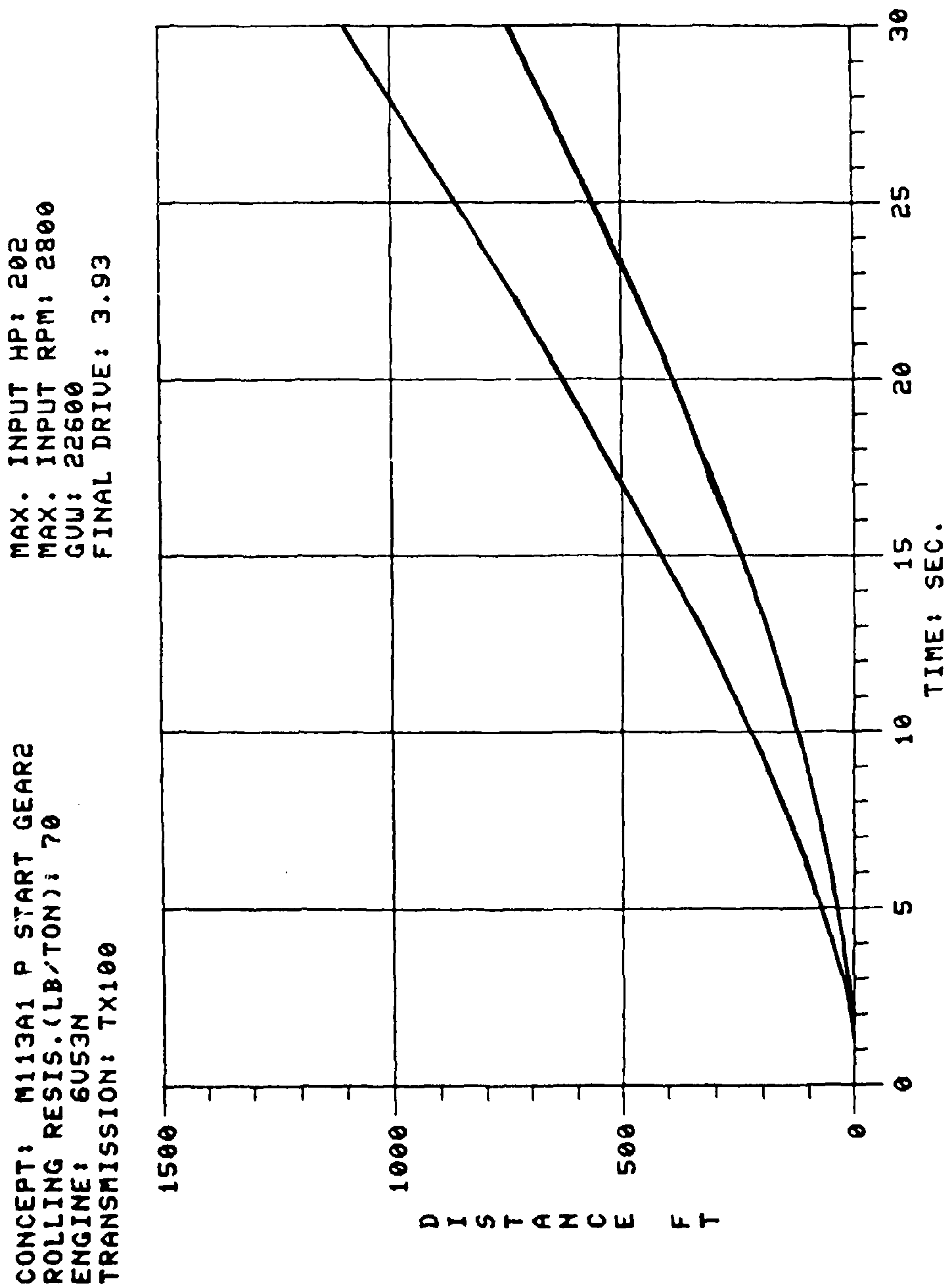

CONCEPT: M113A1 P START GEAR2
ROLLING RESIS.(LB/TON): 70
ENGINE: 6V53N
TRANSMISSION: TX100
MAX. INPUT HP: 202
MAX. INPUT RPM: 2800
GVW: 22600
FINAL DRIVE: 3.93
DISTANCE FT
1500
1000
500
0
0
5
10
15
20
25
30
TIME: SEC.

FIGURE C-2

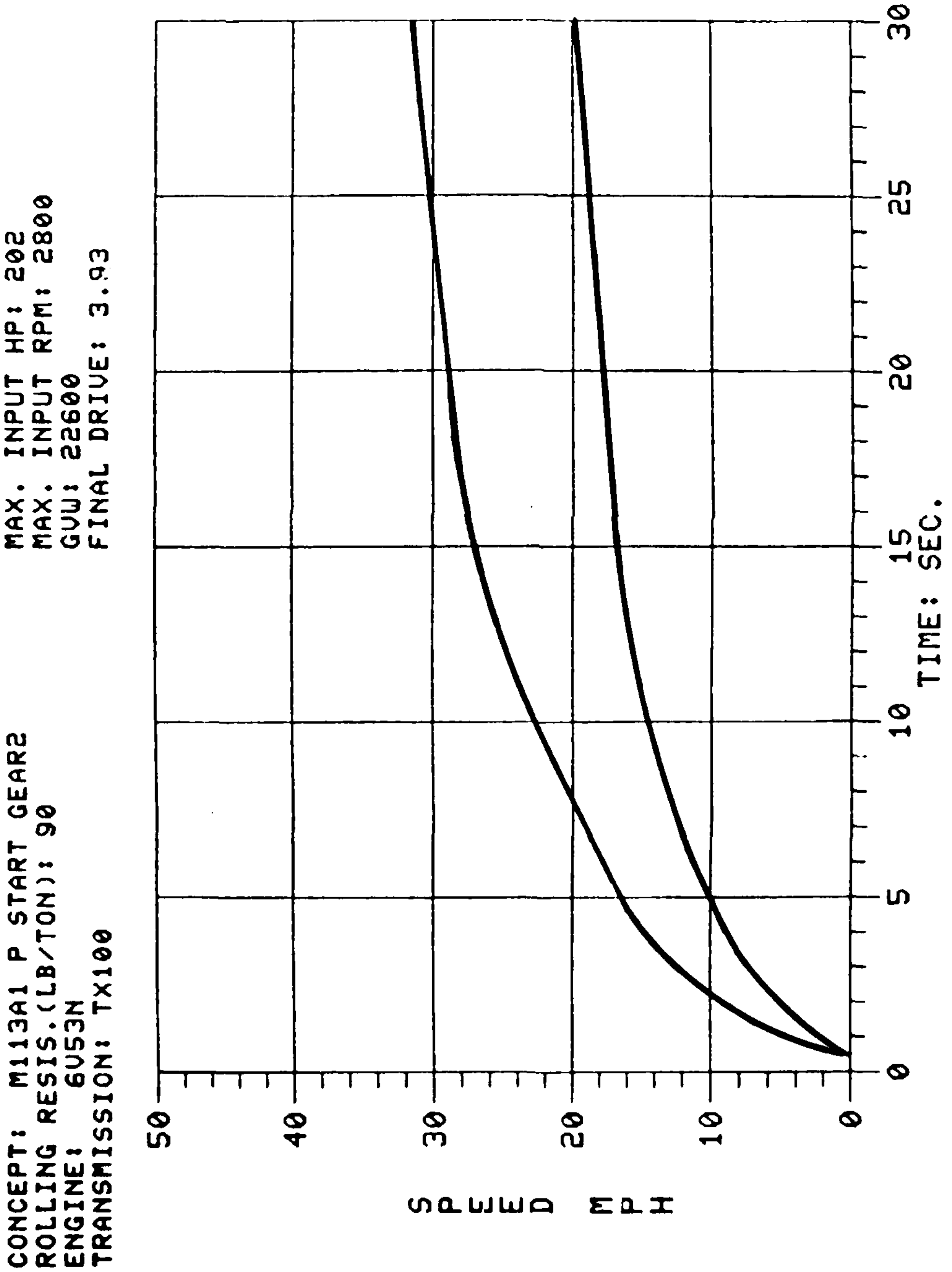

CONCEPT: M113A1 P START GEAR2
ROLLING RESIS.(LB/TON): 90
ENGINE: 6V53N
TRANSMISSION: TX100
MAX. INPUT HP: 202
MAX. INPUT RPM: 2800
GVW: 22600
FINAL DRIVE: 3.93
SPEED MPH
0
10
20
30
40
50
0
5
10
15
20
25
30
TIME: SEC.

FIGURE C-3

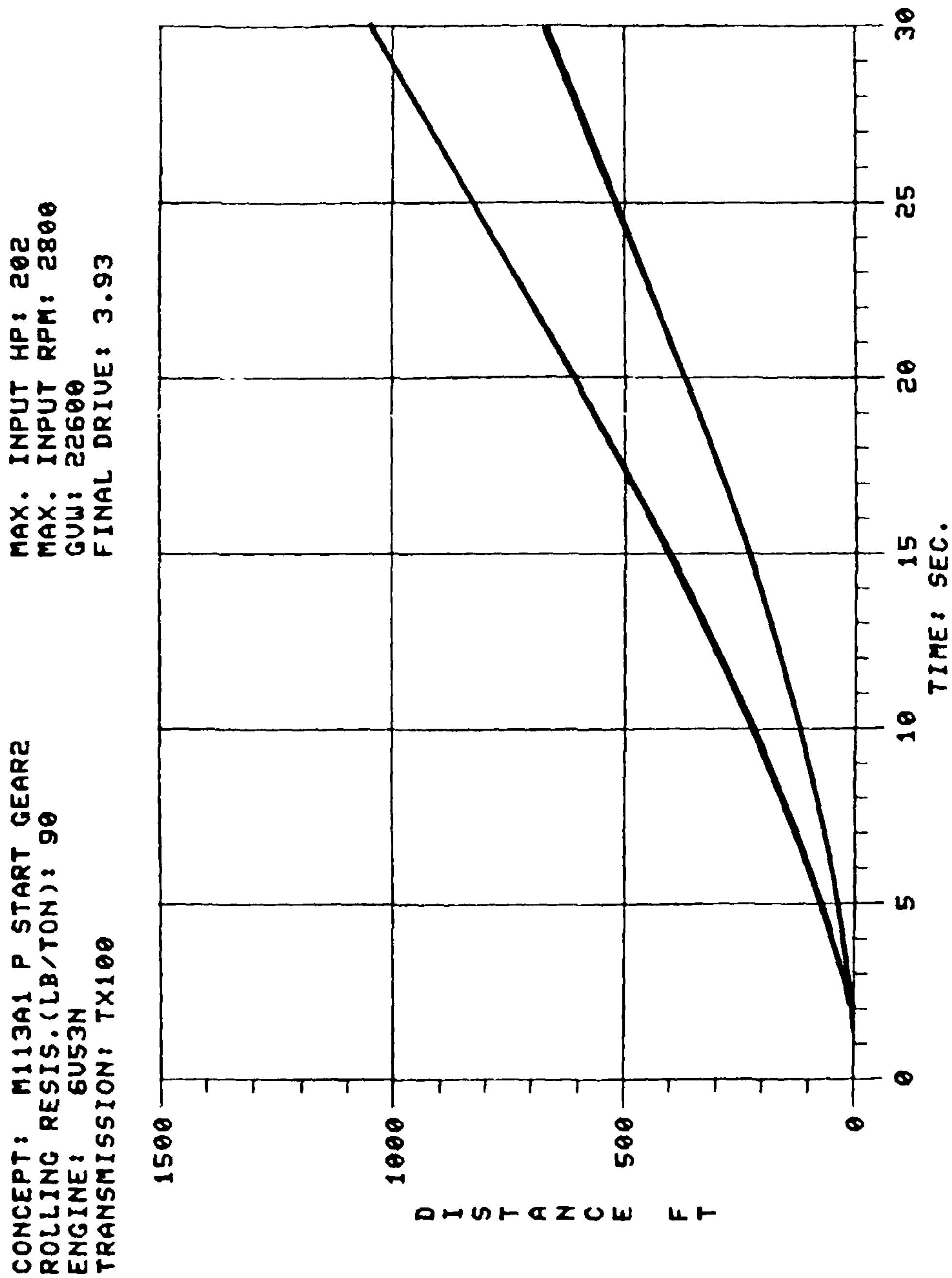

CONCEPT: M113A1 P START GEAR2
ROLLING RESIS.(LB/TON): 90
ENGINE: 6V53N
TRANSMISSION: TX100
MAX. INPUT HP: 202
MAX. INPUT RPM: 2800
GVW: 22600
FINAL DRIVE: 3.93
DISTANCE FT
0
500
1000
1500
TIME: SEC.
0
5
10
15
20
25
30

FIGURE C-4

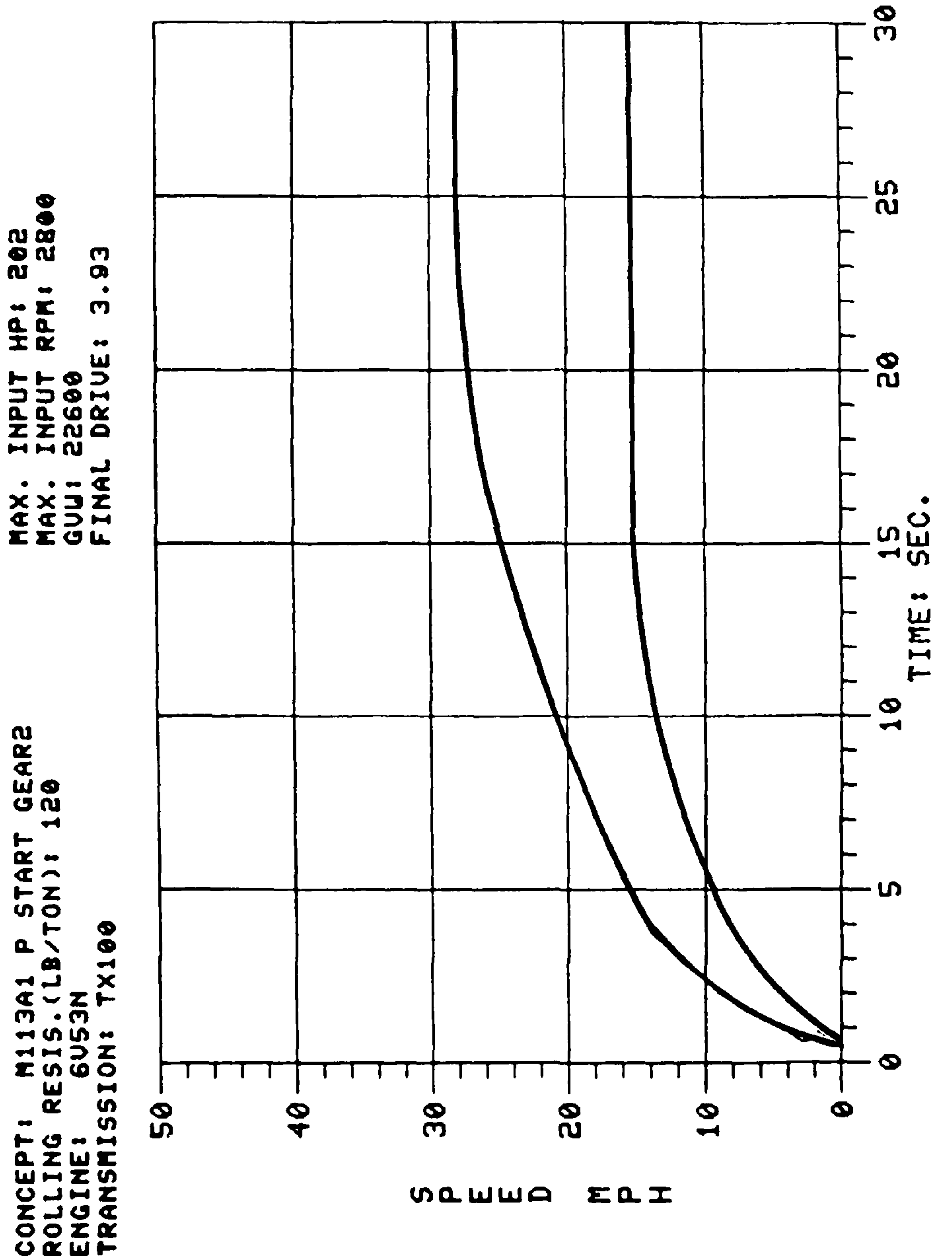

CONCEPT: M113A1 P START GEAR2
ROLLING RESIS.(LB/TON): 120
ENGINE: 6V53N
TRANSMISSION: TX100
MAX. INPUT HP: 202
MAX. INPUT RPM: 2800
GVW: 22600
FINAL DRIVE: 3.93
SPEED MPH
0
10
20
30
40
50
TIME: SEC.
0
5
10
15
20
25
30

FIGURE C-5

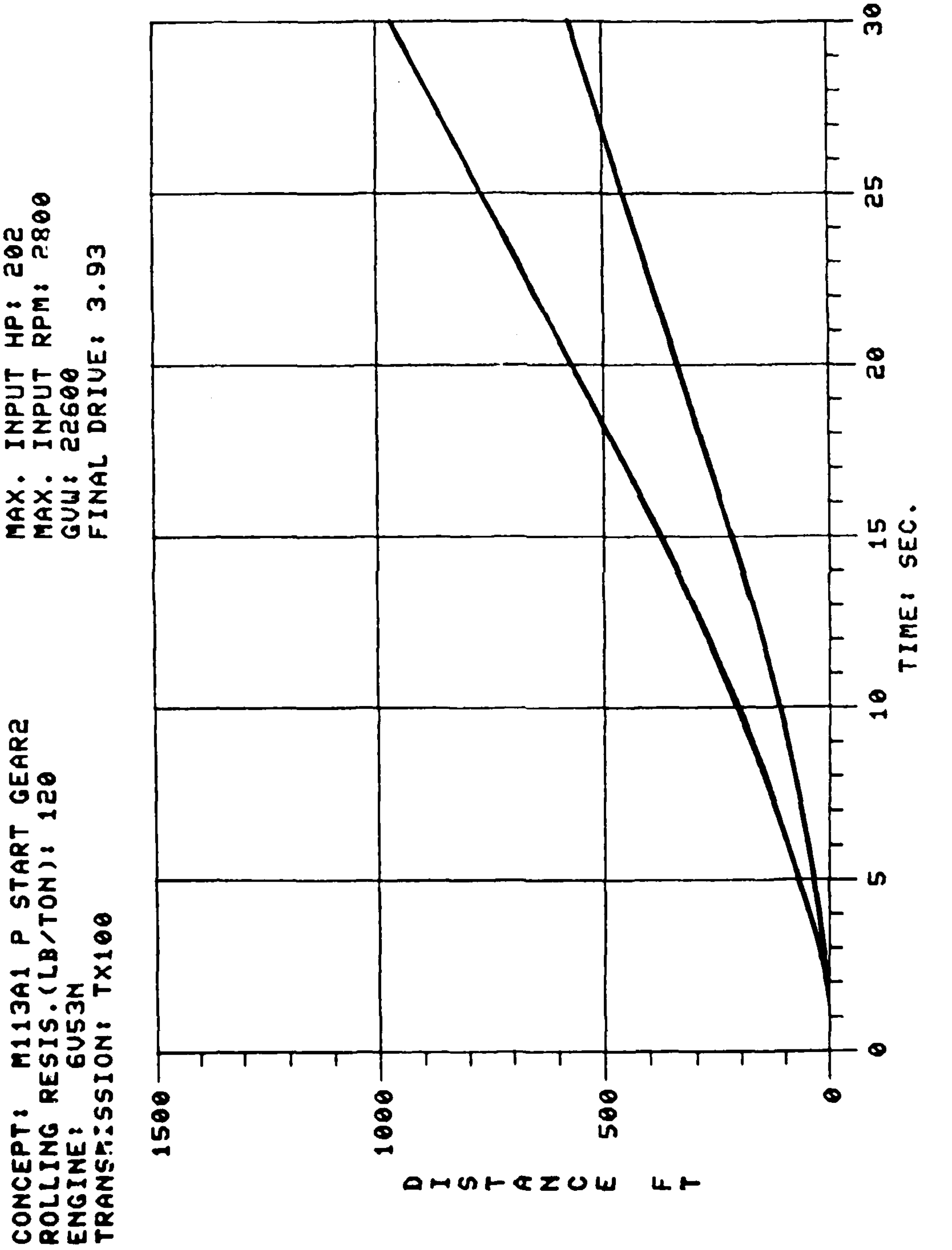

CONCEPT: M113A1 P START GEAR2
ROLLING RESIS.(LB/TON): 120
ENGINE: 6V53N
TRANSMISSION: TX100
MAX. INPUT HP: 202
MAX. INPUT RPM: 2800
GVW: 22600
FINAL DRIVE: 3.93
DISTANCE FT
1500
1000
500
0
0
5
10
15
20
25
30
TIME: SEC.

FIGURE C-6

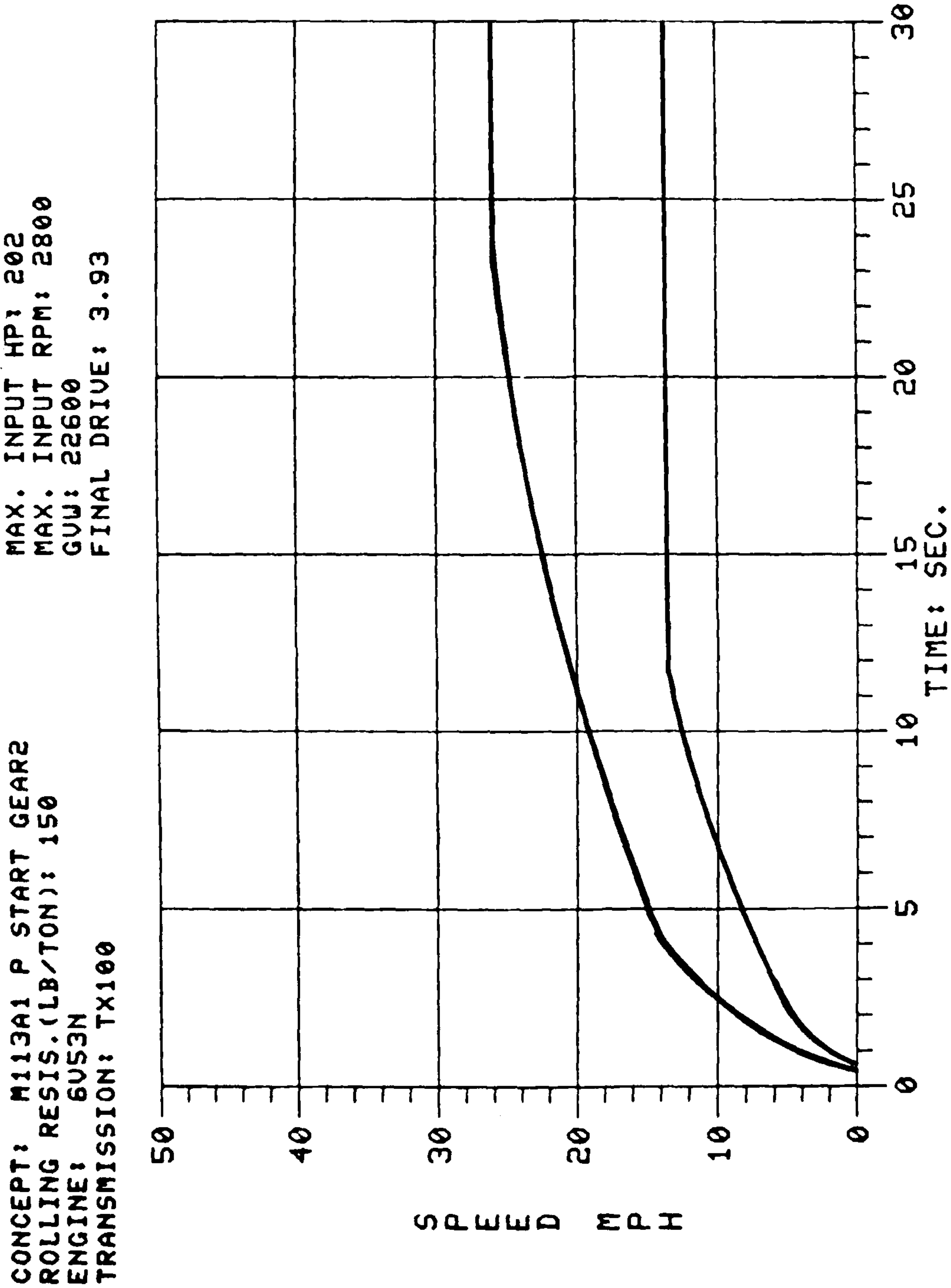

CONCEPT: M113A1 P START GEAR2
ROLLING RESIS.(LB/TON): 150
ENGINE: 6V53N
TRANSMISSION: TX100
MAX. INPUT HP: 202
MAX. INPUT RPM: 2800
GVW: 22600
FINAL DRIVE: 3.93
SPEED MPH
0
10
20
30
40
50
0
5
10
15
20
25
30
TIME: SEC.

FIGURE C-7

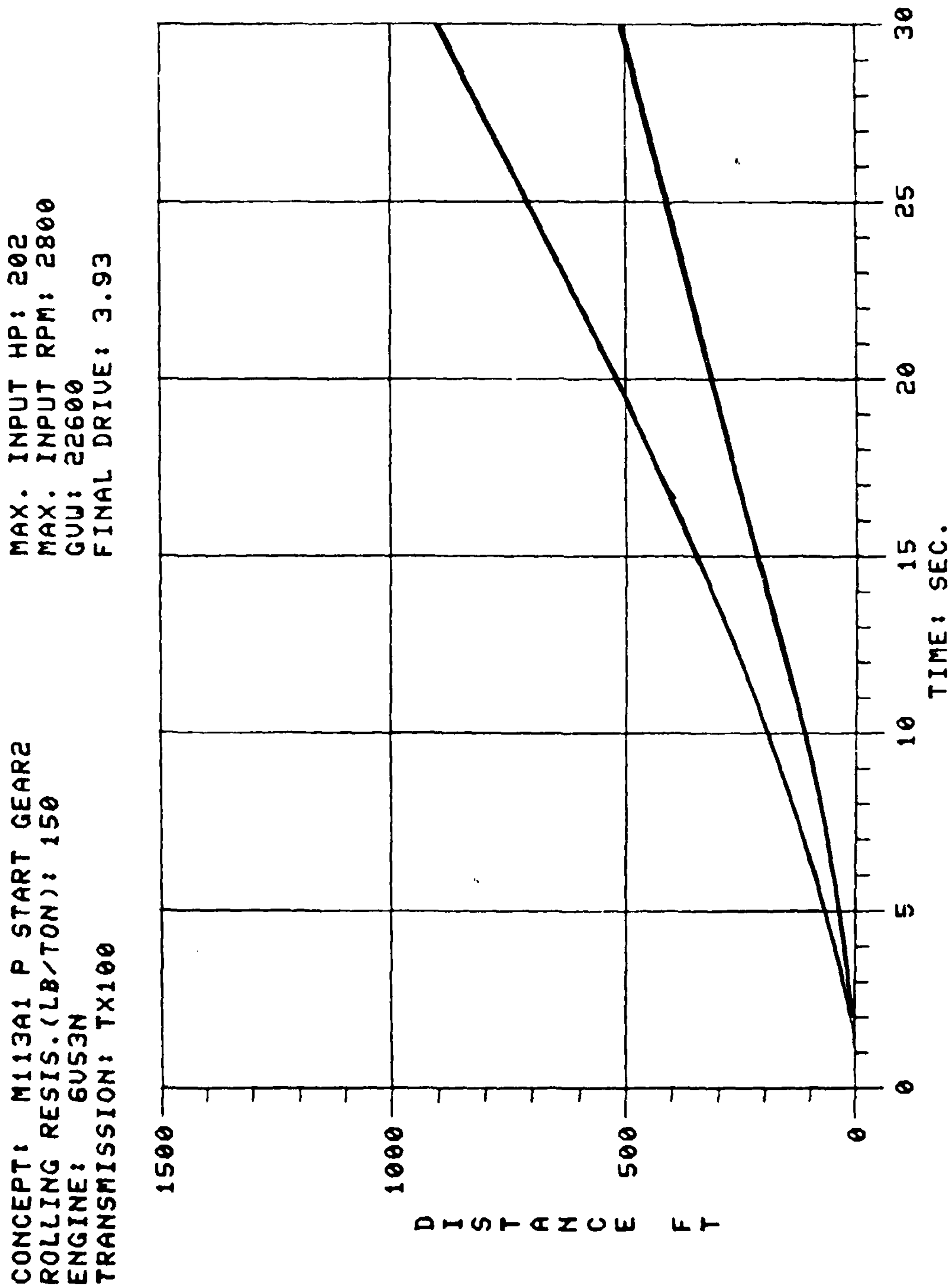
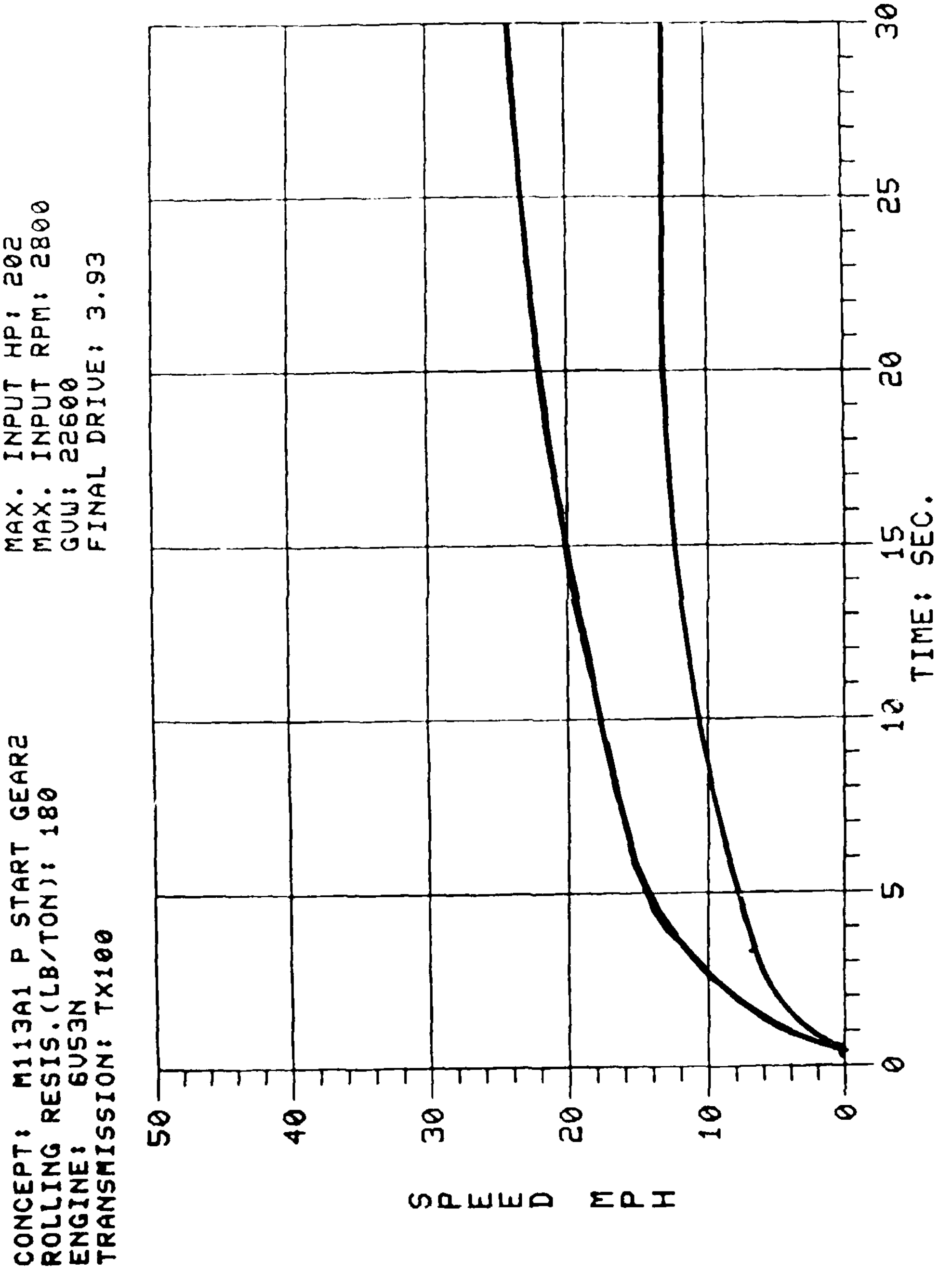

CONCEPT: M113A1 P START GEAR2
ROLLING RESIS.(LB/TON): 150
ENGINE: 6V53N
TRANSMISSION: TX100
MAX. INPUT HP: 202
MAX. INPUT RPM: 2800
GVW: 22600
FINAL DRIVE: 3.93
DISTANCE FT
1500
1000
500
0
0
5
10
15
20
25
30
TIME: SEC.

FIGURE C-8



CONCEPT: M113A1 P START GEAR2
ROLLING RESIS.(LB/TON): 180
ENGINE: 6V53N
TRANSMISSION: TX100
MAX. INPUT HP: 202
MAX. INPUT RPM: 2800
GVW: 22600
FINAL DRIVE: 3.93
SPEED MPH
0
10
20
30
40
50
TIME: SEC.
0
5
10
15
20
25
30

FIGURE C-9

CONCEPT: M113A1 P START GEAR2
ROLLING RESIS.(LB/TON): 180
ENGINE: 6V53N
TRANSMISSION: TX100

MAX. INPUT HP: 202
MAX. INPUT RPM: 2800
GVW: 22600
FINAL DRIVE: 3.93

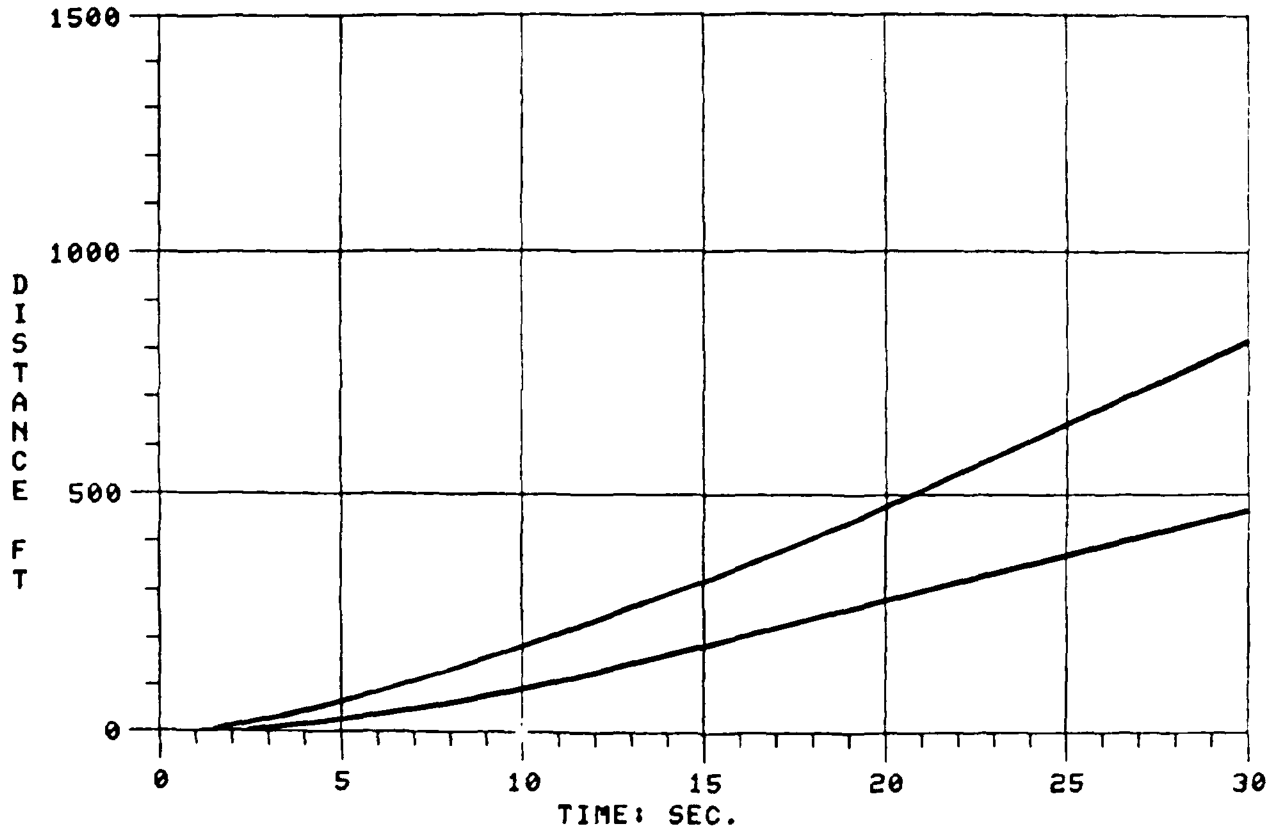


FIGURE C-10

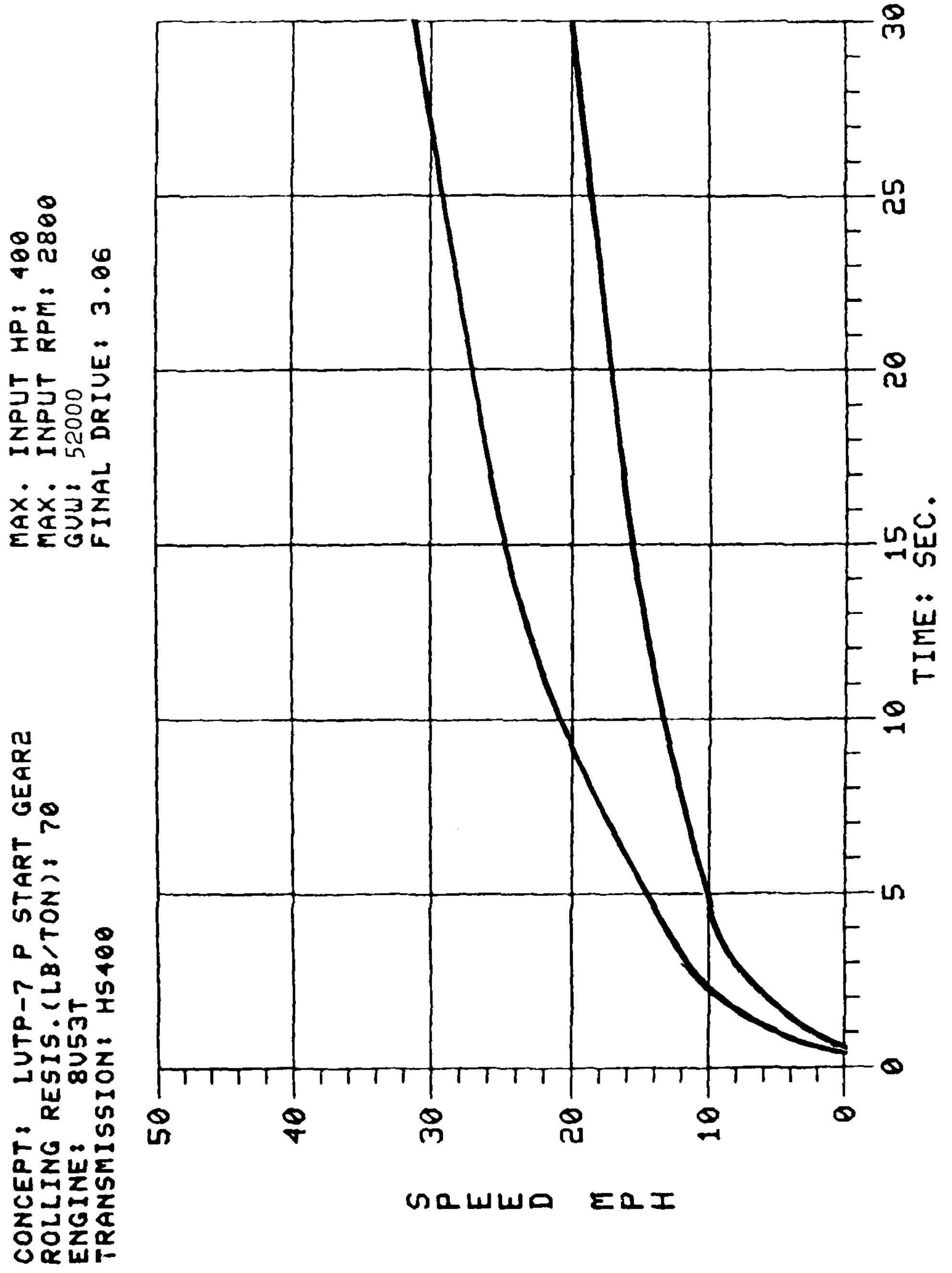

CONCEPT: LVTP-7 P START GEAR2
ROLLING RESIS.(LB/TON): 70
ENGINE: 8V53T
TRANSMISSION: HS400
MAX. INPUT HP: 400
MAX. INPUT RPM: 2800
GVW: 52000
FINAL DRIVE: 3.06
SPEED MPH
TIME: SEC.
0
10
20
30
40
50
5
15
25

FIGURE C-11

CONCEPT: LVTP-7 P START GEAR2
ROLLING RESIS.(LB/TON): 70
ENGINE: 8V53T
TRANSMISSION: HS400

MAX. INPUT HP: 400
MAX. INPUT RPM: 2800
GVW: 52000
FINAL DRIVE: 3.06

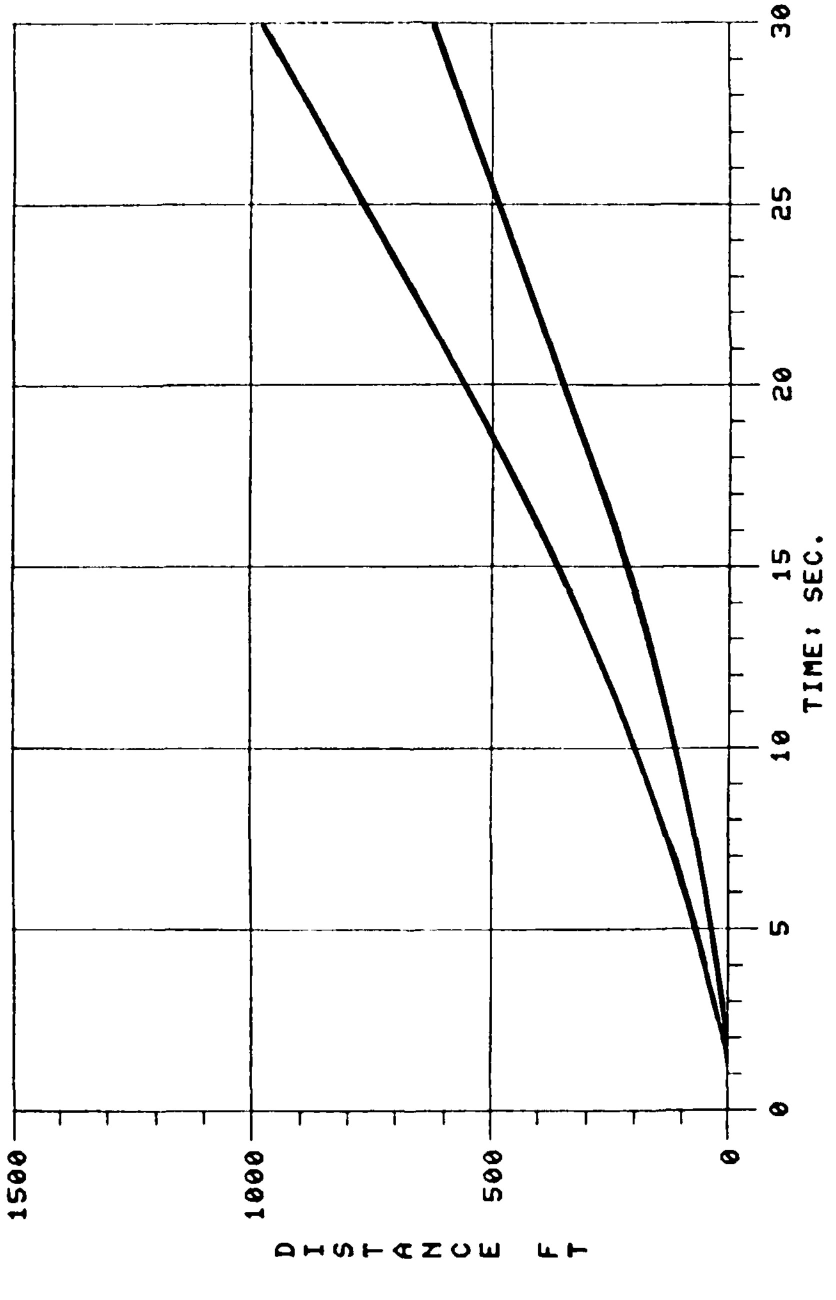


FIGURE C-12

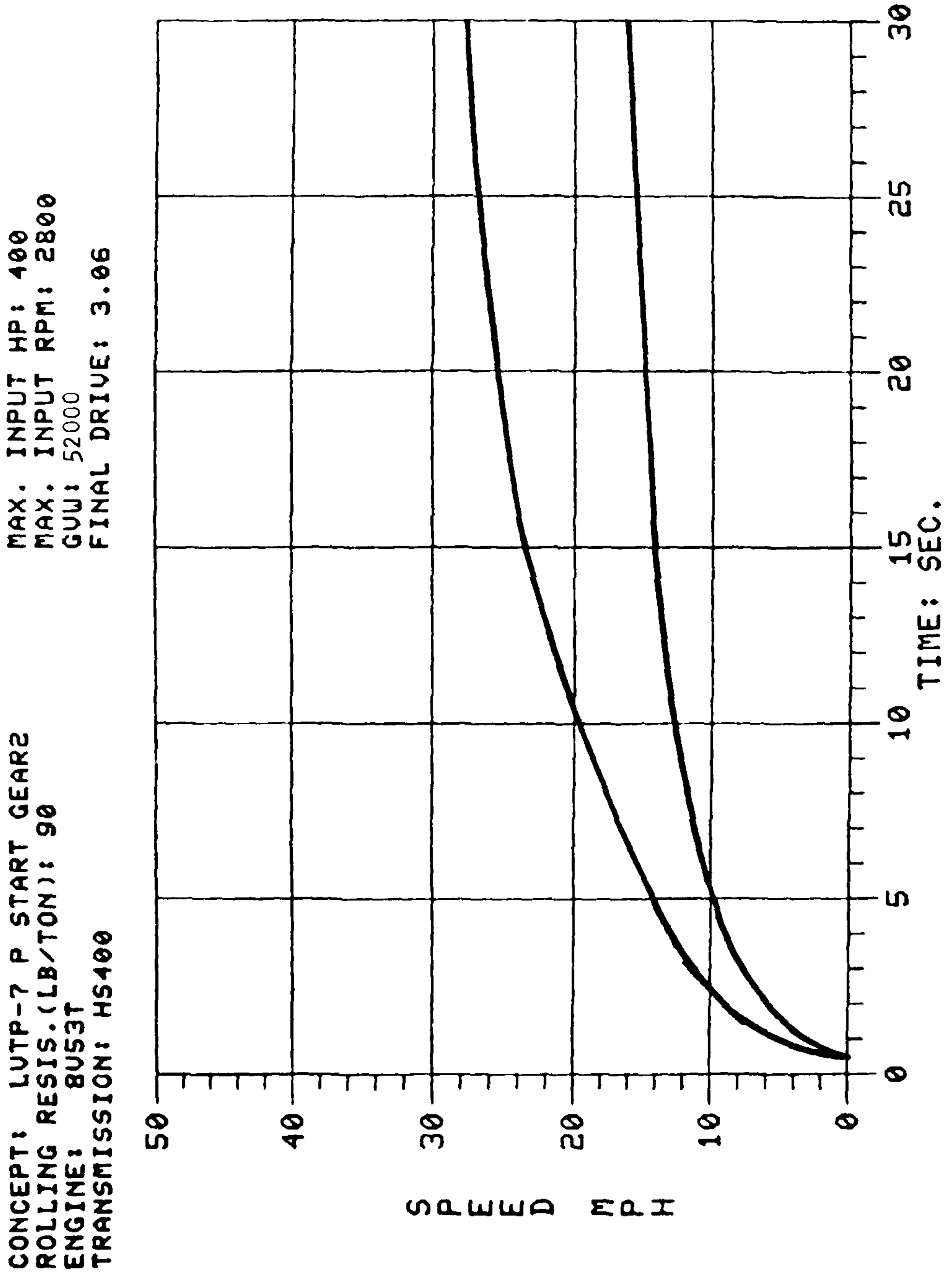

CONCEPT: LVTP-7 P START GEAR2
ROLLING RESIS.(LB/TON): 90
ENGINE: 8V53T
TRANSMISSION: HS400
MAX. INPUT HP: 400
MAX. INPUT RPM: 2800
GVW: 52000
FINAL DRIVE: 3.06
SPEED MPH
0
10
20
30
40
50
TIME: SEC.
0
5
10
15
20
25
30

FIGURE C-13

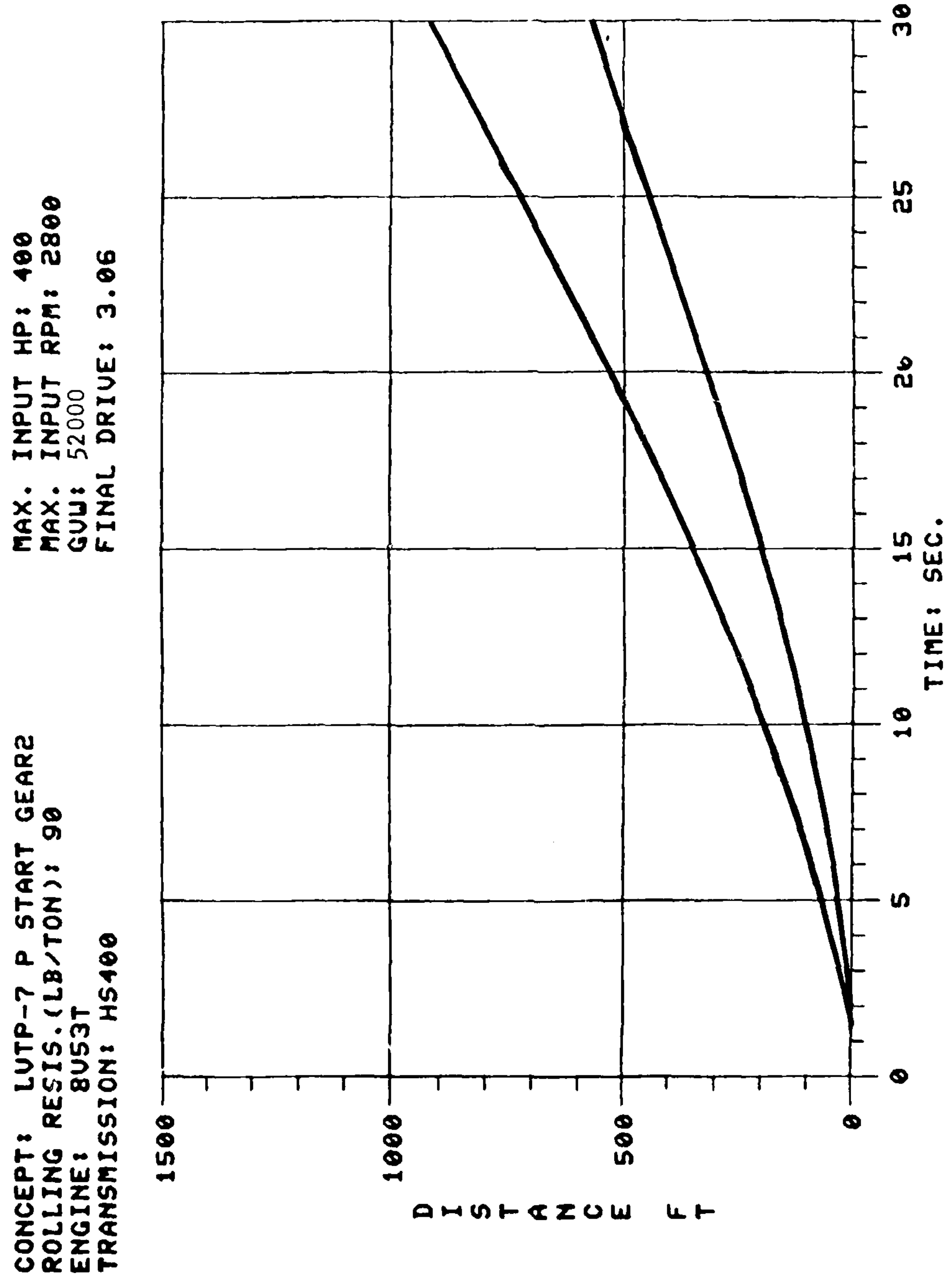

CONCEPT: LVTP-7 P START GEAR2
ROLLING RESIS.(LB/TON): 90
ENGINE: 8V53T
TRANSMISSION: HS400
MAX. INPUT HP: 400
MAX. INPUT RPM: 2800
GVW: 52000
FINAL DRIVE: 3.06
DISTANCE FT
1500
1000
500
0
0
5
10
15
20
25
30
TIME: SEC.

FIGURE C-14

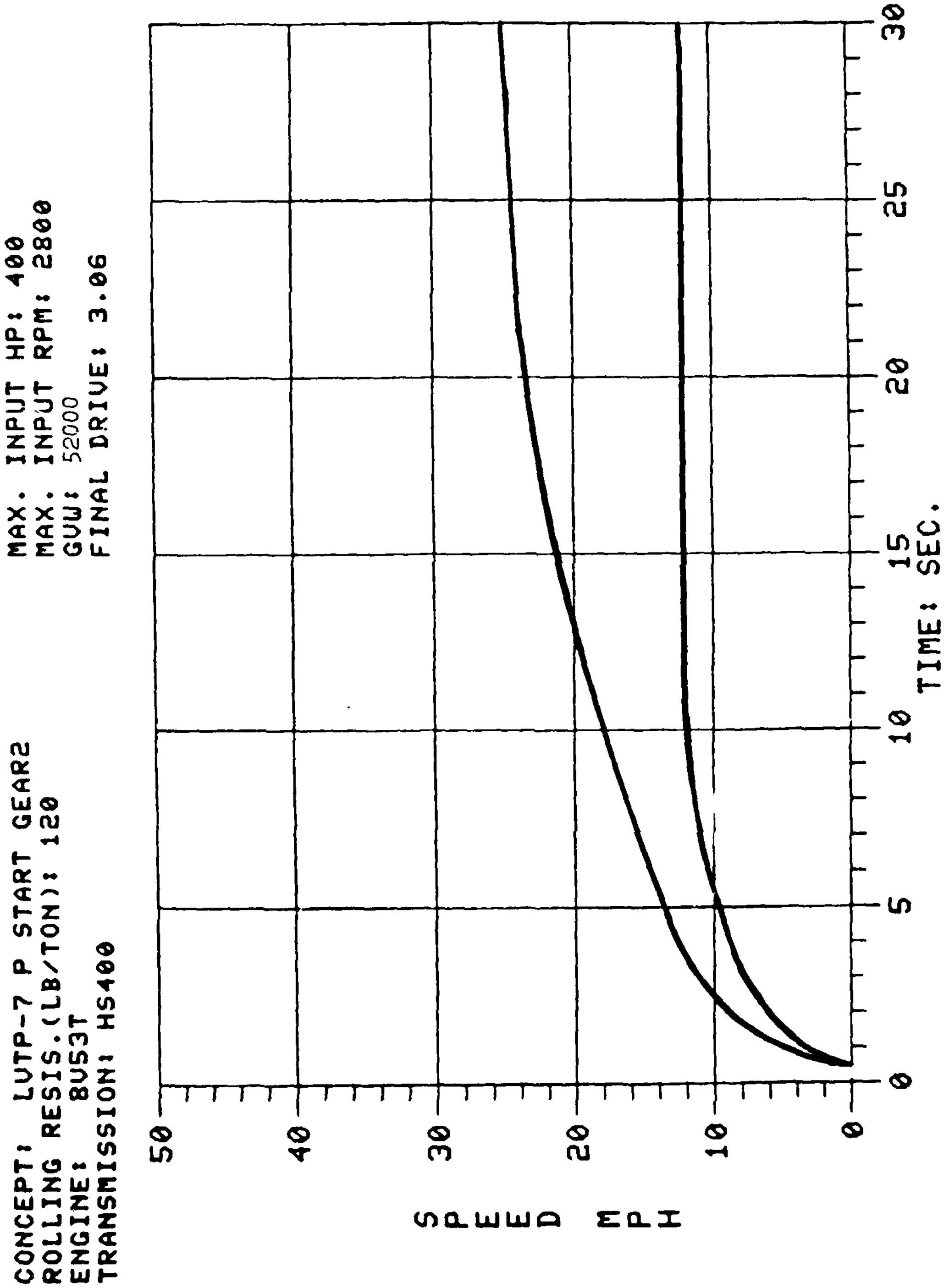

CONCEPT: LUTP-7 P START GEAR2
ROLLING RESIS.(LB/TON): 120
ENGINE: 8V53T
TRANSMISSION: HS400
MAX. INPUT HP: 400
MAX. INPUT RPM: 2800
GVW: 52000
FINAL DRIVE: 3.06
SPEED MPH
0
10
20
30
40
50
TIME: SEC.
0
5
10
15
20
25
30

FIGURE C-15

CONCEPT: LVTP-7 P START GEAR2
ROLLING RESIS.(LB/TON): 120
ENGINE: 8V53T
TRANSMISSION: HS400

MAX. INPUT HP: 400
MAX. INPUT RPM: 2800
GVW: 52000
FINAL DRIVE: 3.06

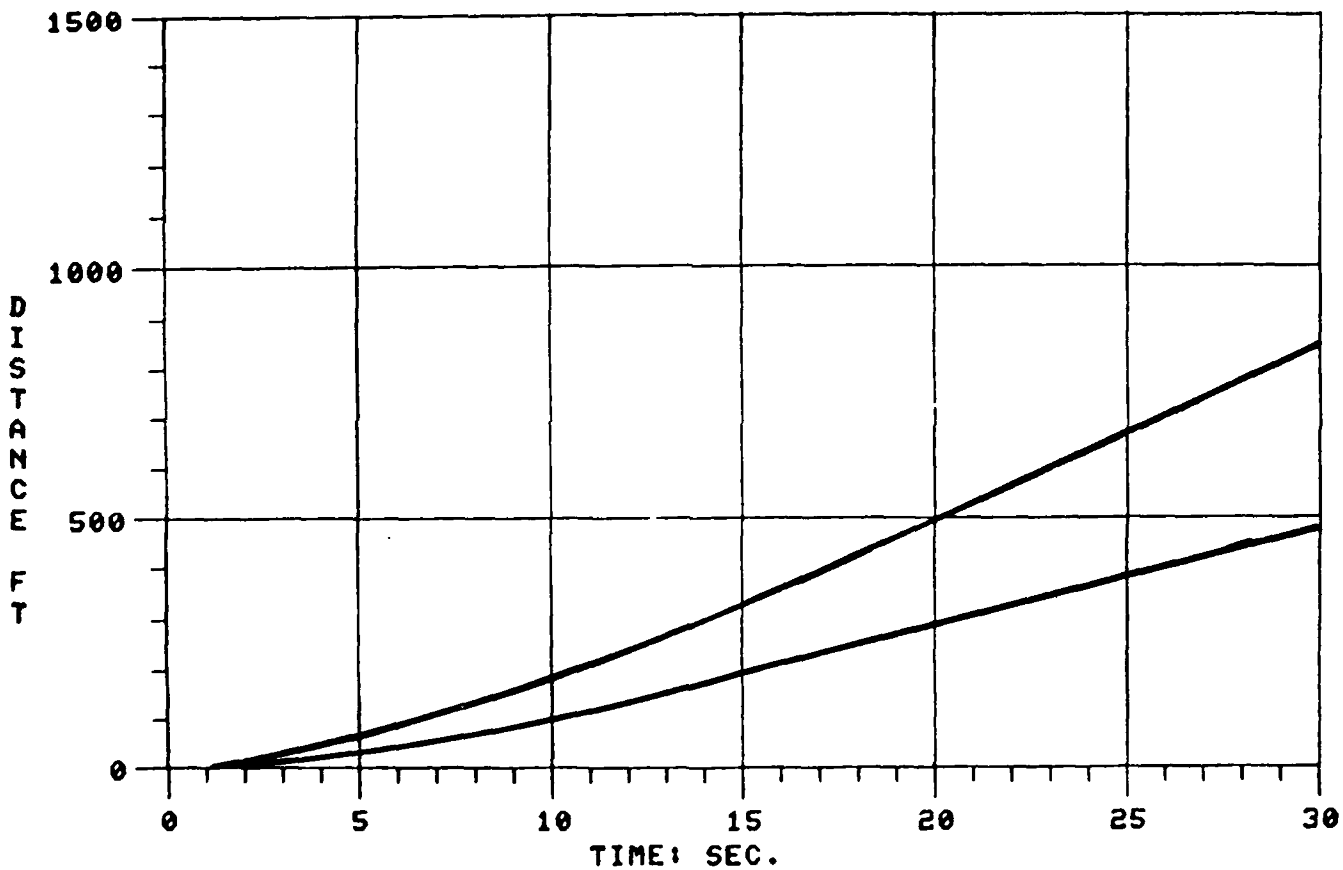
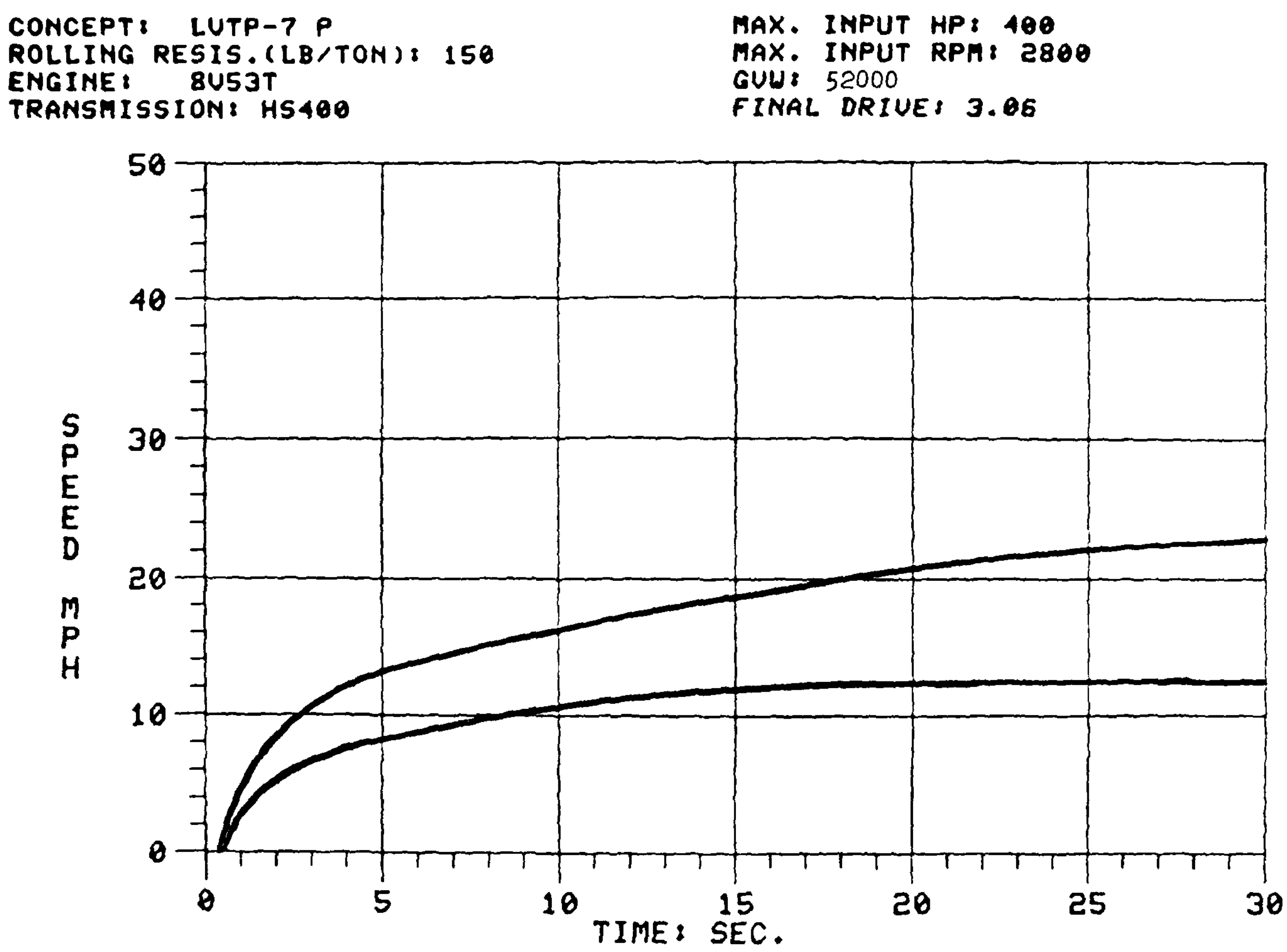


FIGURE C-16



CONCEPT: LVTP-7 P
ROLLING RESIS.(LB/TON): 150
ENGINE: 8V53T
TRANSMISSION: HS400
MAX. INPUT HP: 400
MAX. INPUT RPM: 2800
GVW: 52000
FINAL DRIVE: 3.06
SPEED MPH
0
10
20
30
40
50
TIME: SEC.
0
5
10
15
20
25
30

FIGURE C-17

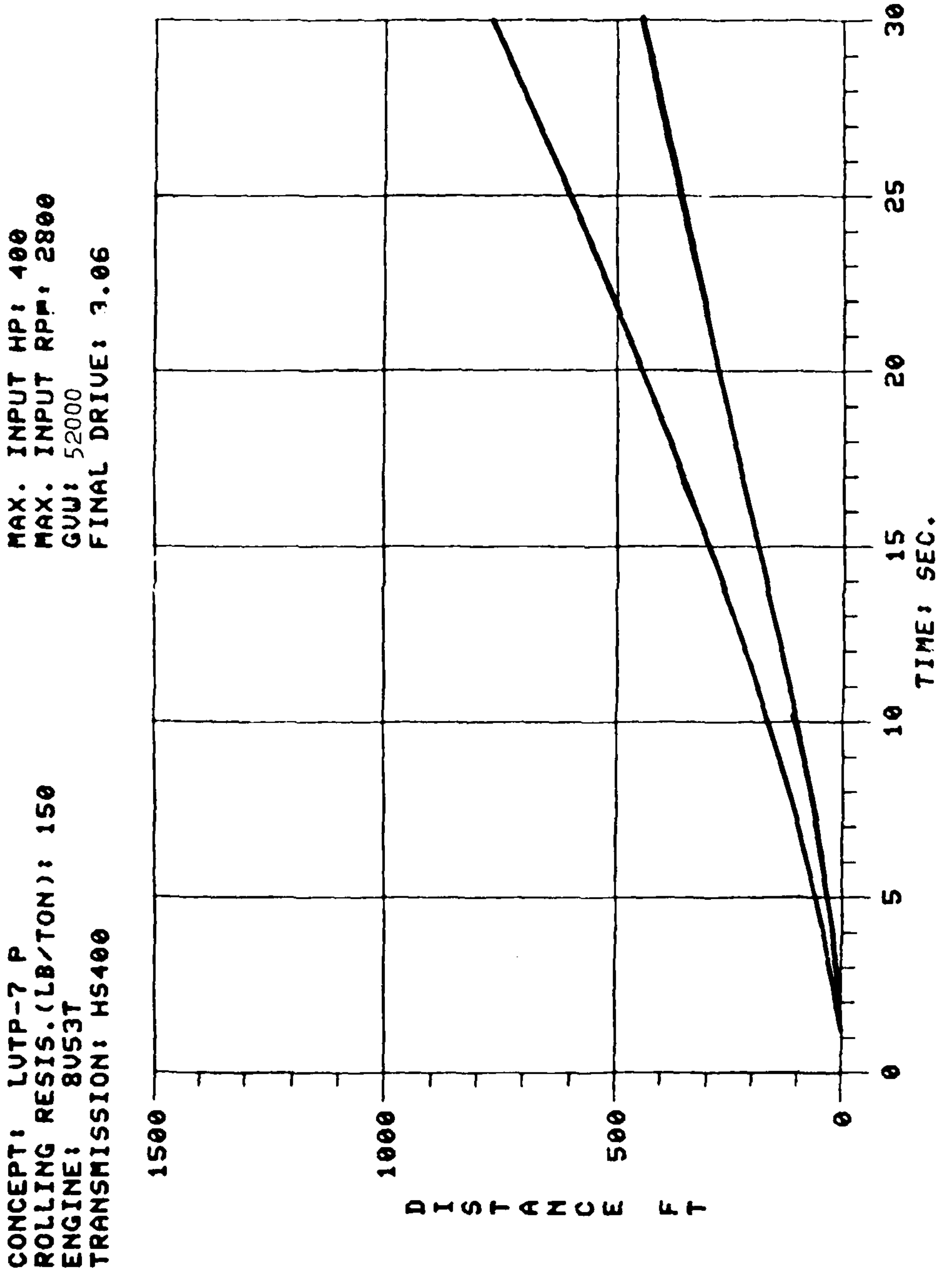

CONCEPT: LVTP-7 P
ROLLING RESIS.(LB/TON): 150
ENGINE: 8V53T
TRANSMISSION: HS400
MAX. INPUT HP: 400
MAX. INPUT RPM: 2800
GVW: 52000
FINAL DRIVE: 3.06
DISTANCE FT
1500
1000
500
0
TIME: SEC.
0
5
10
15
20
25
30

FIGURE C-18

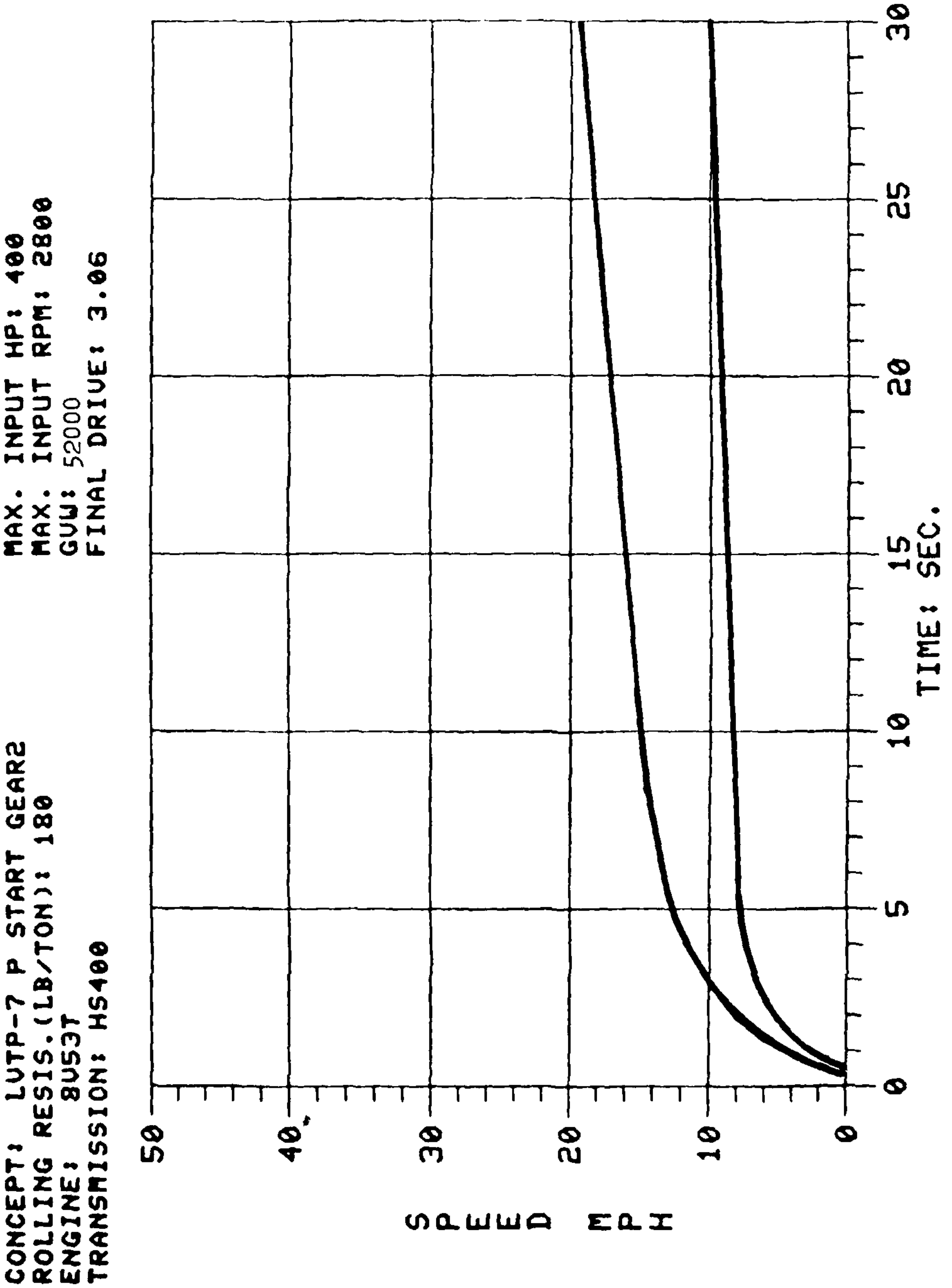

CONCEPT: LVTP-7 P START GEAR2
ROLLING RESIS.(LB/TON): 180
ENGINE: 8V53T
TRANSMISSION: HS400
MAX. INPUT HP: 400
MAX. INPUT RPM: 2800
GVW: 52000
FINAL DRIVE: 3.06
SPEED MPH
0
10
20
30
40
50
TIME: SEC.
0
5
10
15
20
25
30

FIGURE C-19

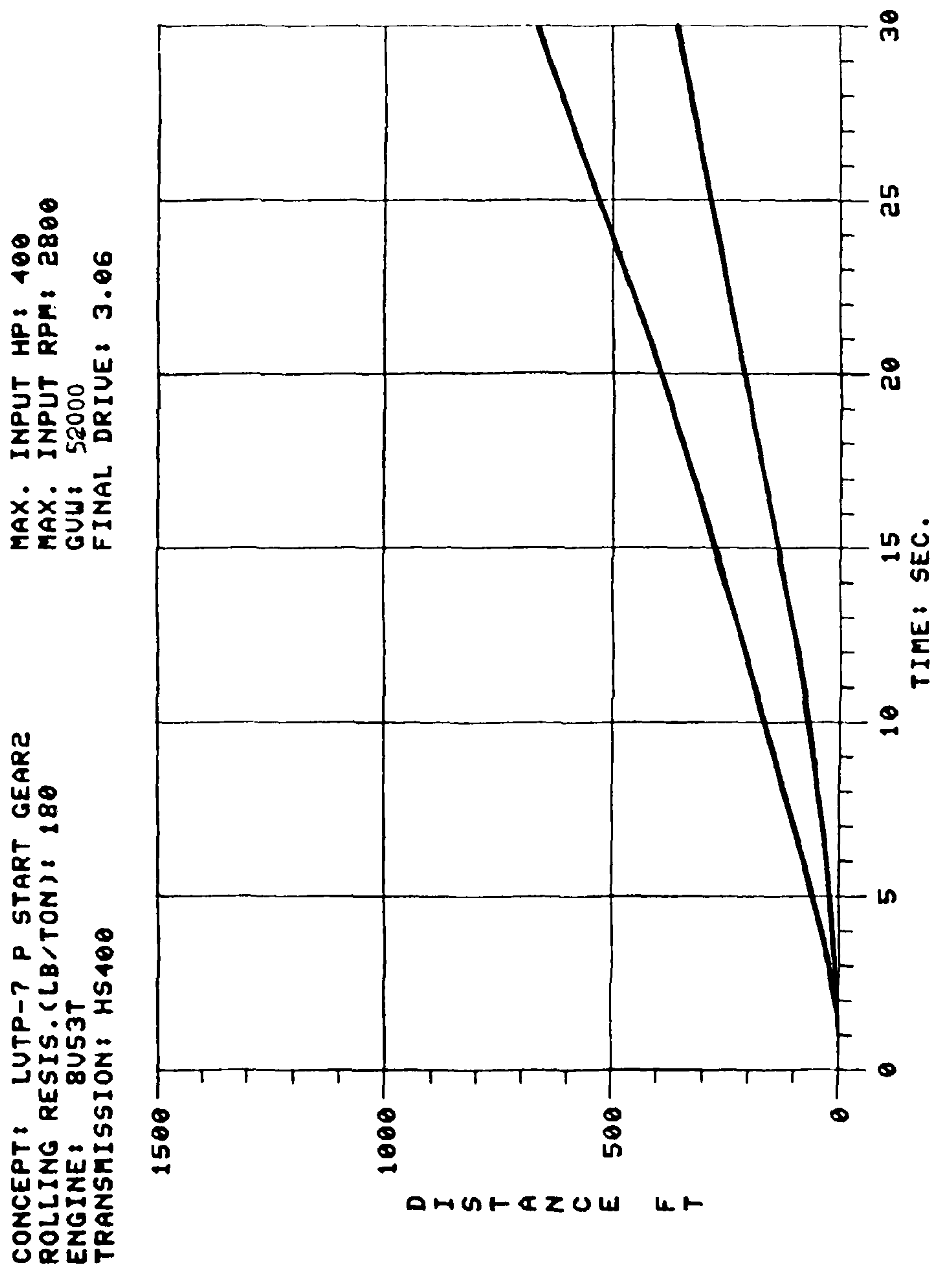

CONCEPT: LVTP-7 P START GEAR2
ROLLING RESIS.(LB/TON): 180
ENGINE: 8V53T
TRANSMISSION: HS400
MAX. INPUT HP: 400
MAX. INPUT RPM: 2800
GVW: 52000
FINAL DRIVE: 3.06
DISTANCE FT
0
500
1000
1500
0
5
10
15
20
25
30
TIME: SEC.

FIGURE C-20

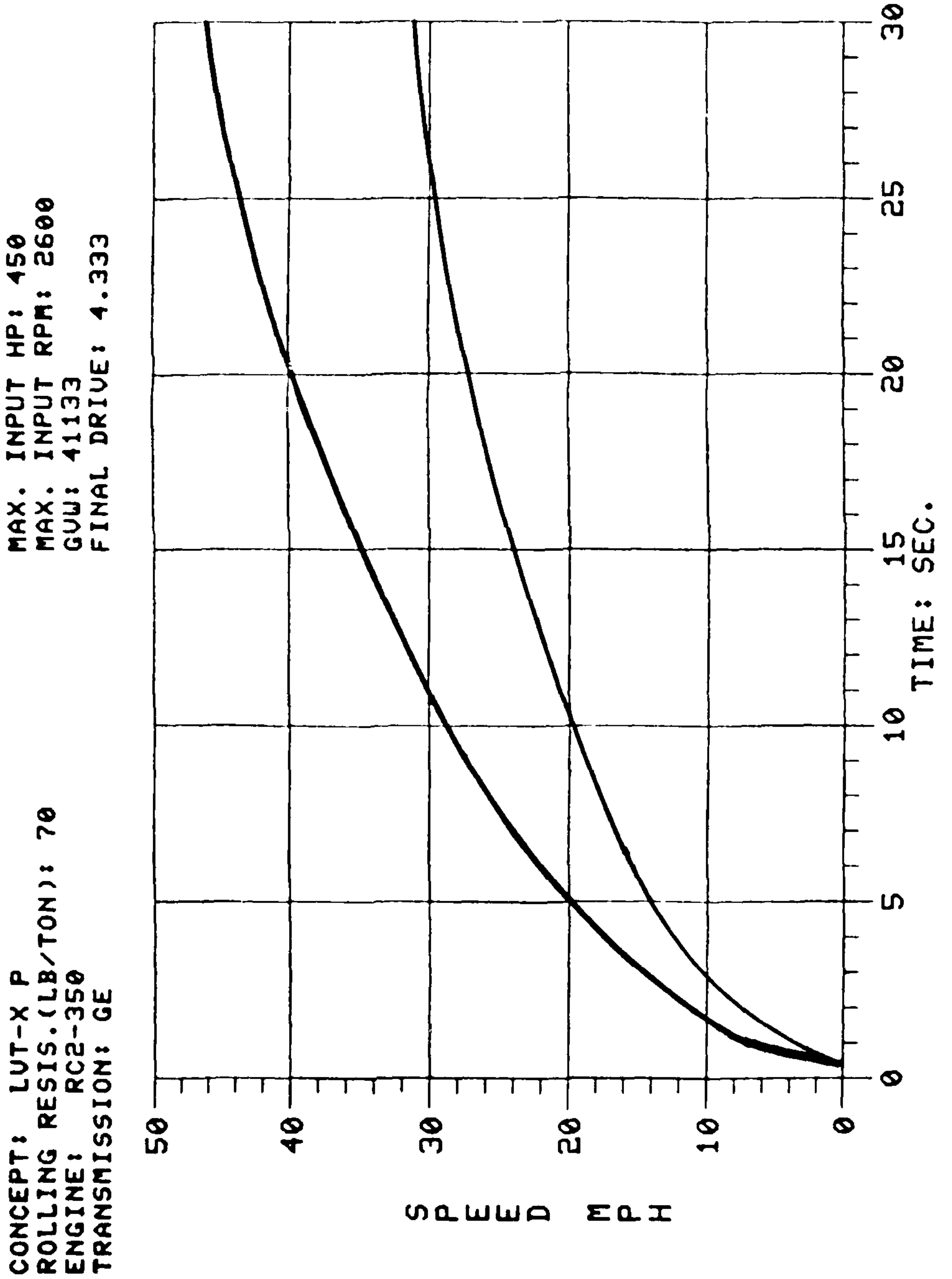

CONCEPT: LVT-X P
ROLLING RESIS.(LB/TON): 70
ENGINE: RC2-350
TRANSMISSION: GE
MAX. INPUT HP: 450
MAX. INPUT RPM: 2600
GVW: 41133
FINAL DRIVE: 4.333
SPEED MPH
0
10
20
30
40
50
0
5
10
15
20
25
30
TIME: SEC.

FIGURE C-21

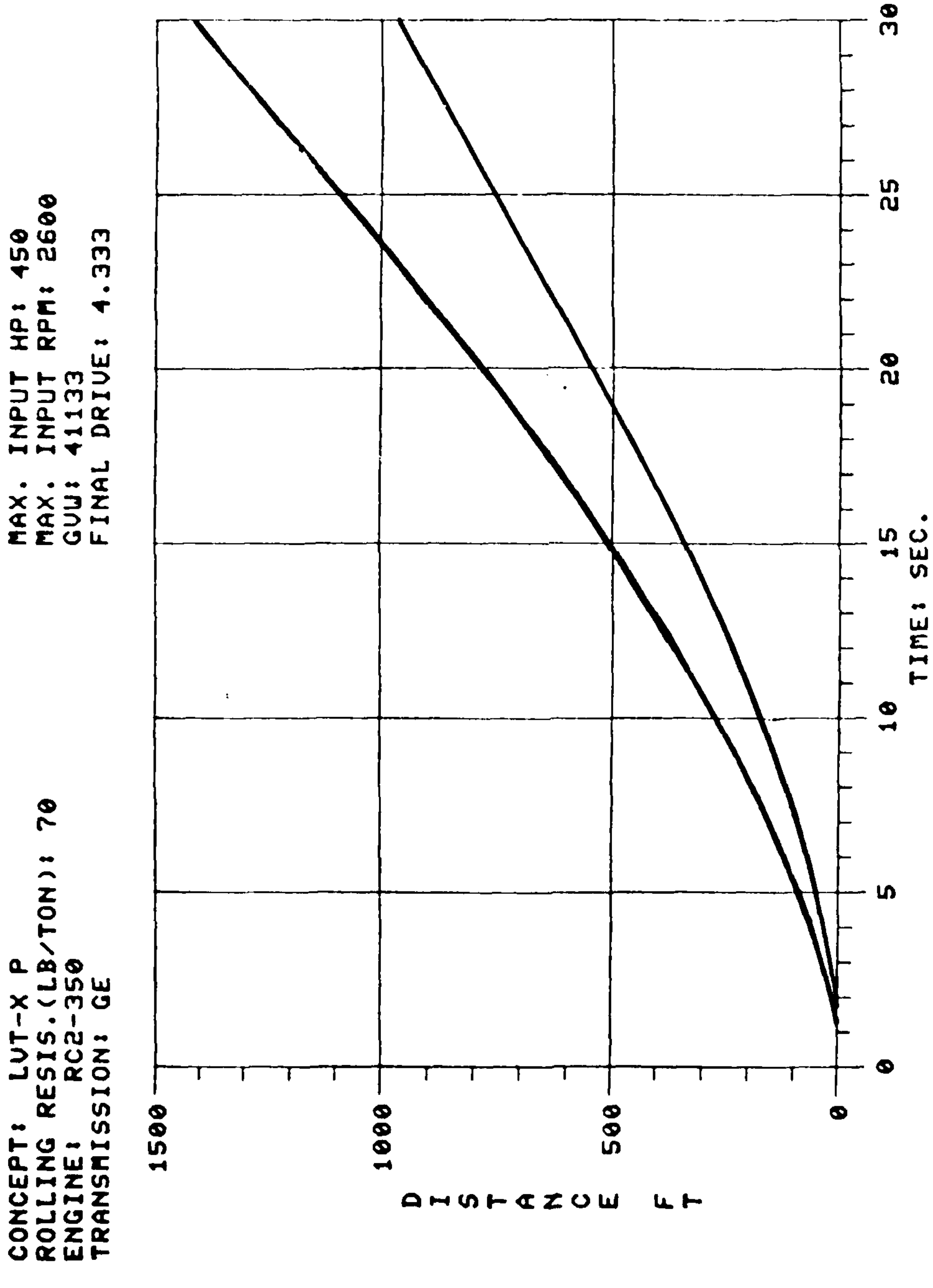

CONCEPT: LVT-X P
ROLLING RESIS.(LB/TON): 70
ENGINE: RC2-350
TRANSMISSION: GE
MAX. INPUT HP: 450
MAX. INPUT RPM: 2600
GVW: 41133
FINAL DRIVE: 4.333
DISTANCE FT
0
500
1000
1500
0
5
10
15
20
25
30
TIME: SEC.

FIGURE C-22

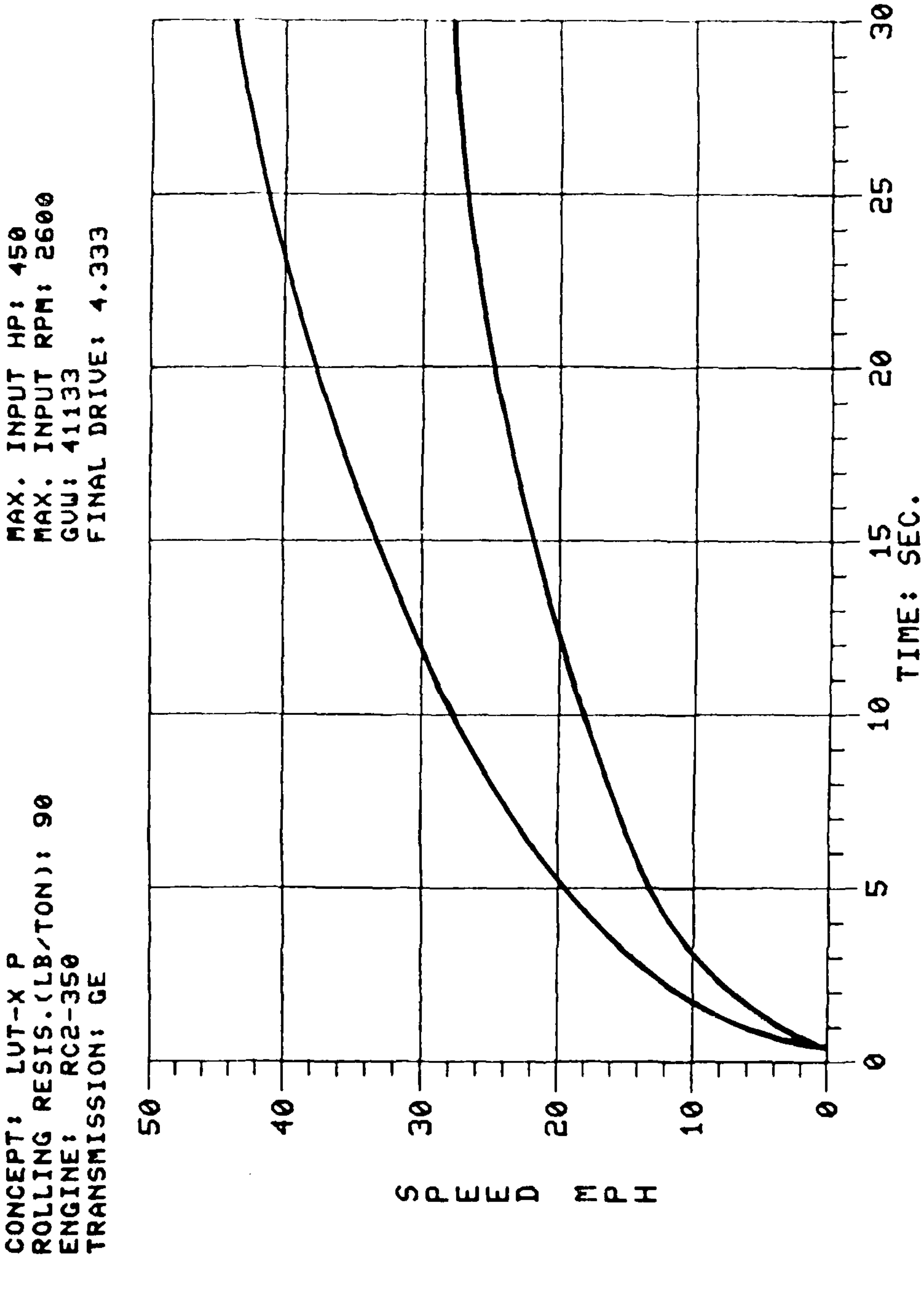

CONCEPT: LVT-X P
ROLLING RESIS.(LB/TON): 90
ENGINE: RC2-350
TRANSMISSION: GE
MAX. INPUT HP: 450
MAX. INPUT RPM: 2600
GVW: 41133
FINAL DRIVE: 4.333
SPEED MPH
0
10
20
30
40
50
TIME: SEC.
0
5
10
15
20
25
30

FIGURE C-23

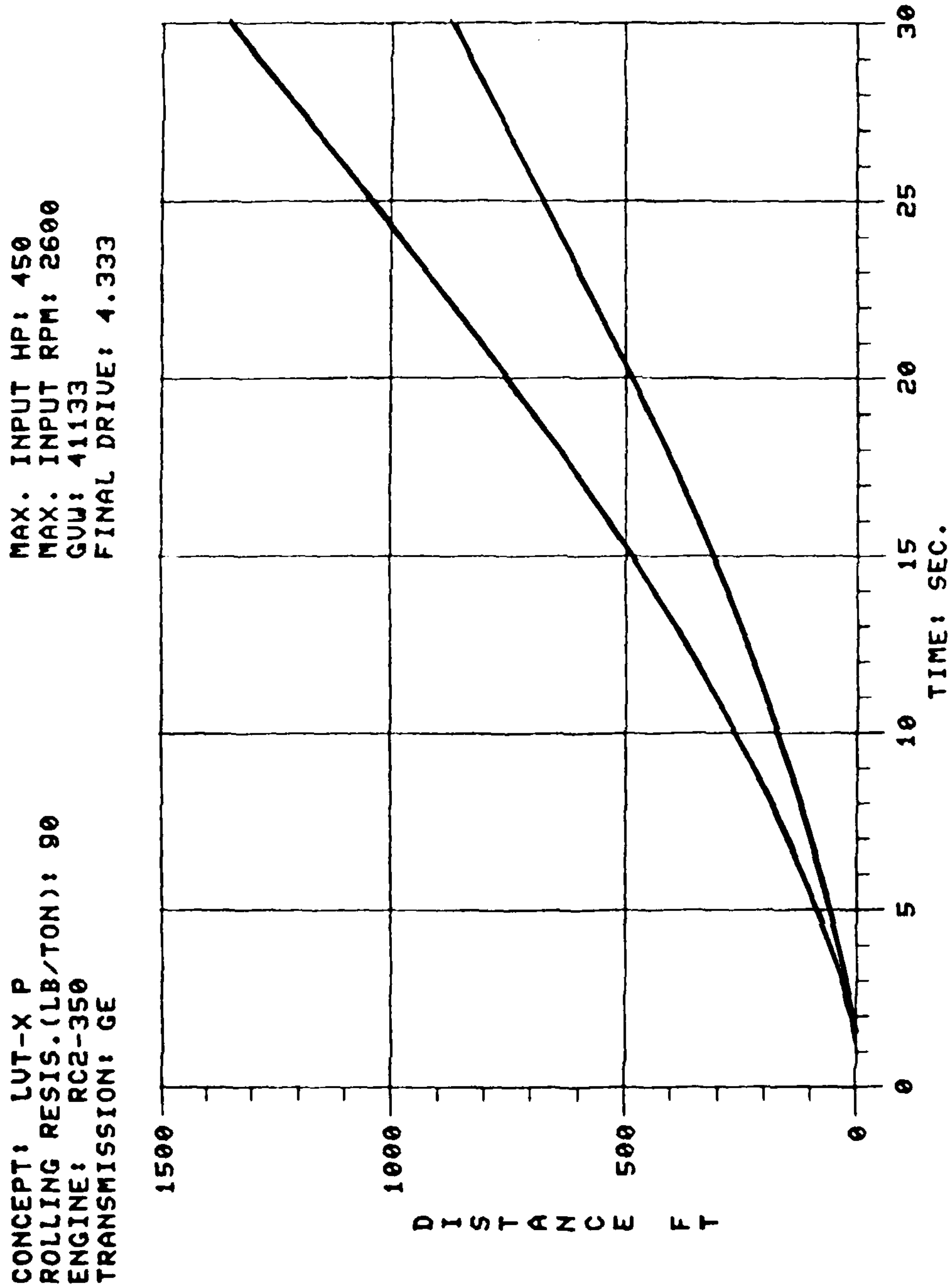

CONCEPT: LVT-X P
ROLLING RESIS.(LB/TON): 90
ENGINE: RC2-350
TRANSMISSION: GE
MAX. INPUT HP: 450
MAX. INPUT RPM: 2600
GVW: 41133
FINAL DRIVE: 4.333
DISTANCE FT
0
500
1000
1500
TIME: SEC.
0
5
10
15
20
25
30

FIGURE C-24

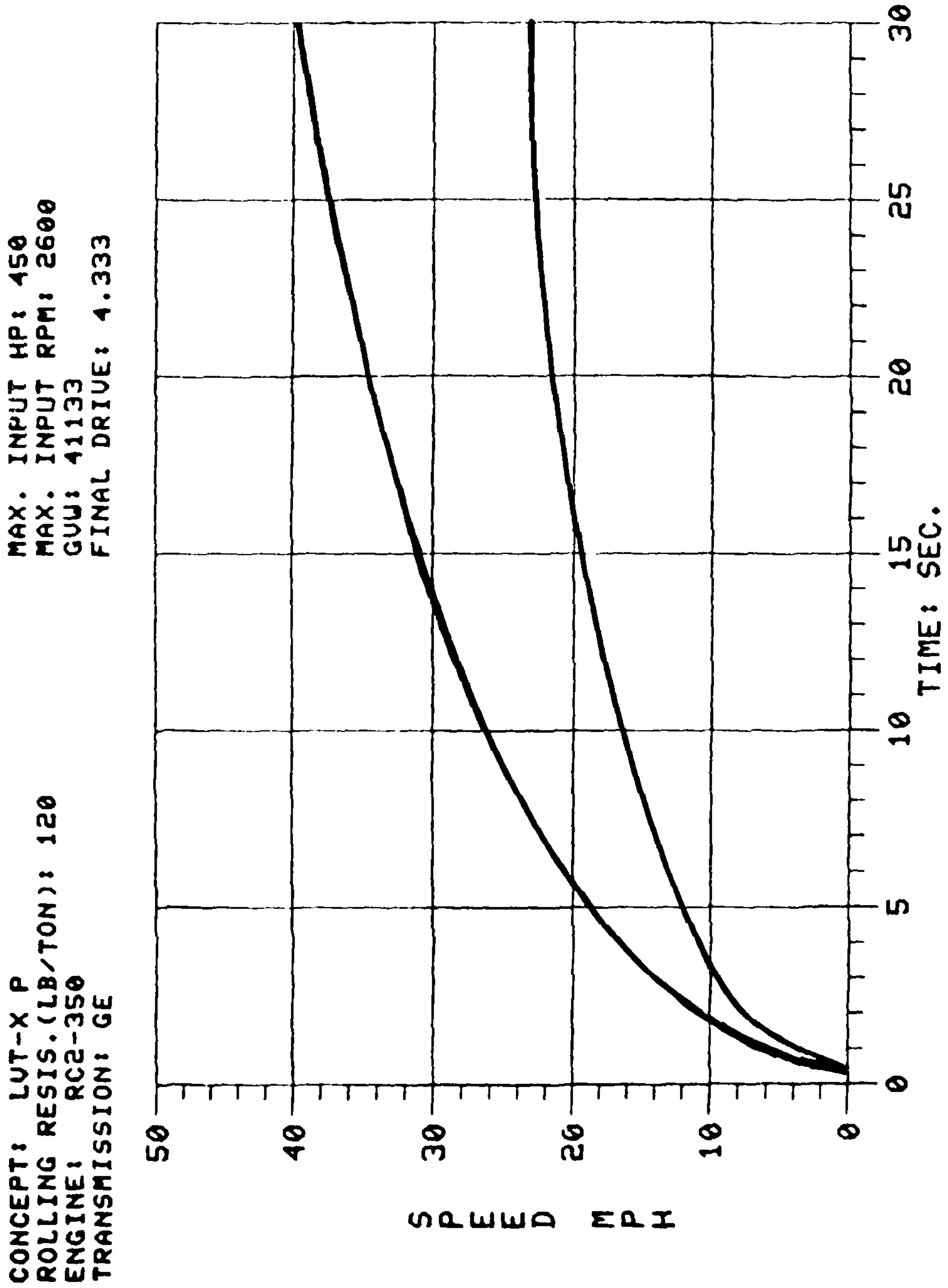

CONCEPT: LVT-X P
ROLLING RESIS.(LB/TON): 120
ENGINE: RC2-350
TRANSMISSION: GE
MAX. INPUT HP: 450
MAX. INPUT RPM: 2600
GVW: 41133
FINAL DRIVE: 4.333
SPEED MPH
0
10
20
30
40
50
TIME: SEC.
0
5
10
15
20
25
30

FIGURE C-25

CONCEPT: LVT-X P
ROLLING RESIS.(LB/TON): 120
ENGINE: RC2-35A
TRANSMISSION: GE

MAX. INPUT HP: 450
MAX. INPUT RPM: 2600
GVW: 41133
FINAL DRIVE: 4.333

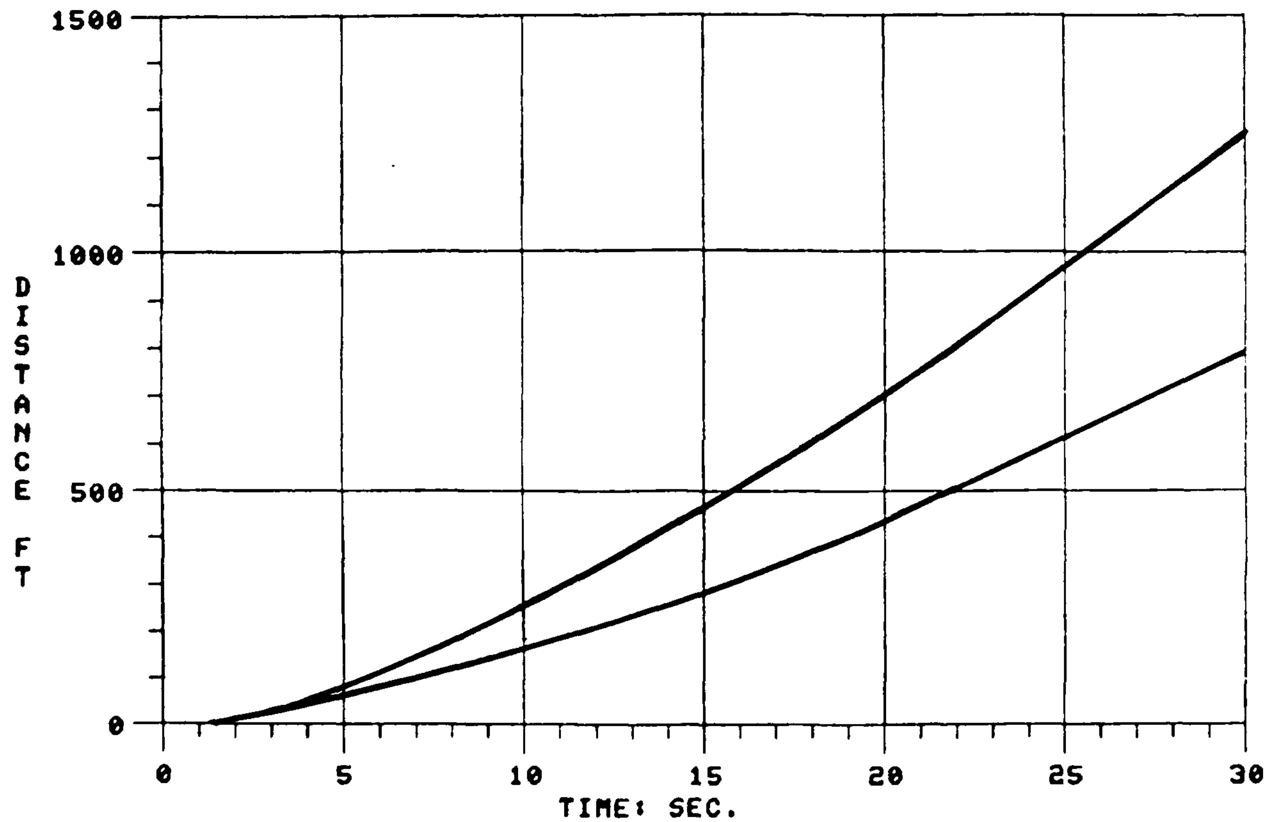


FIGURE C-26

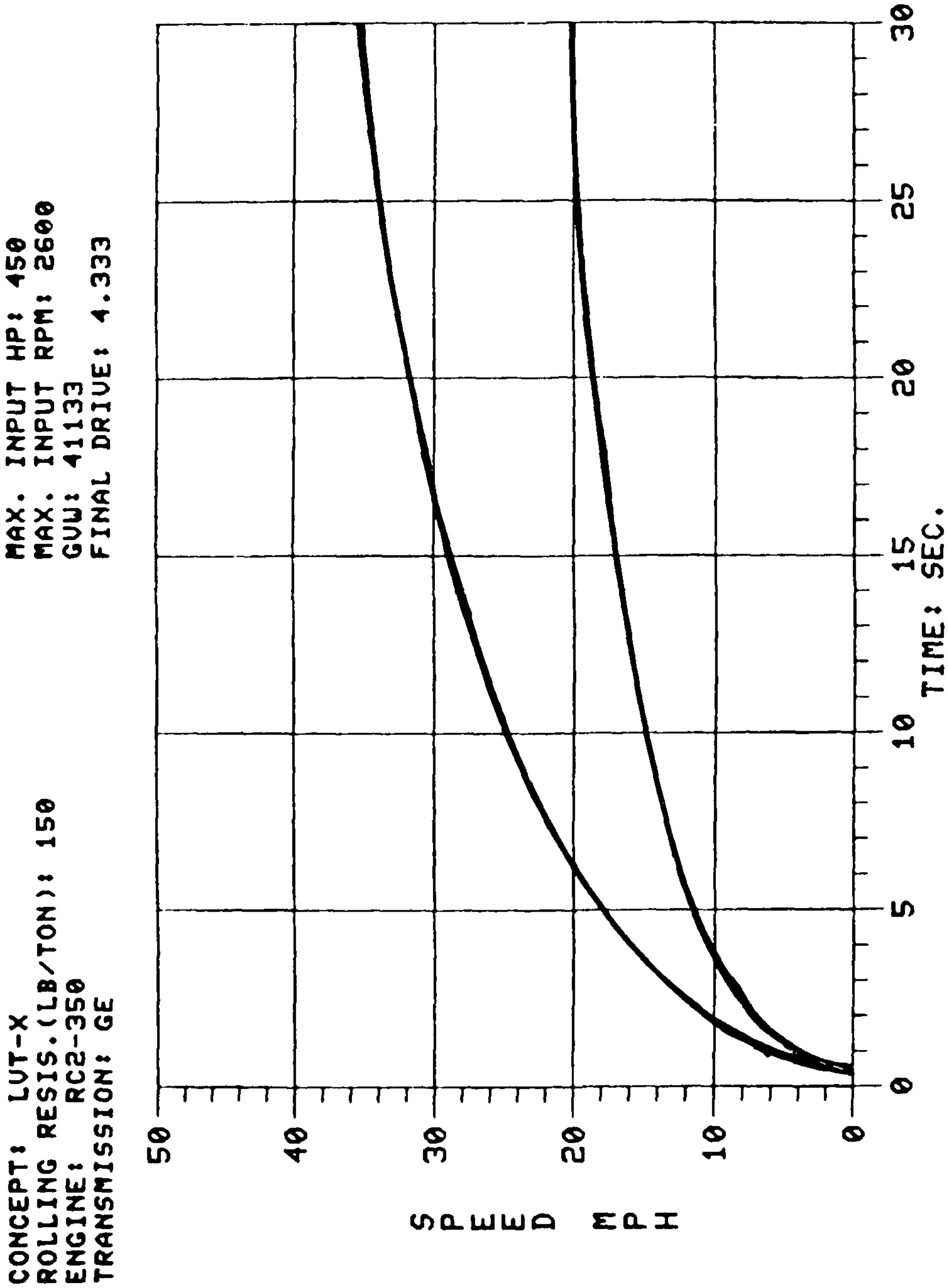
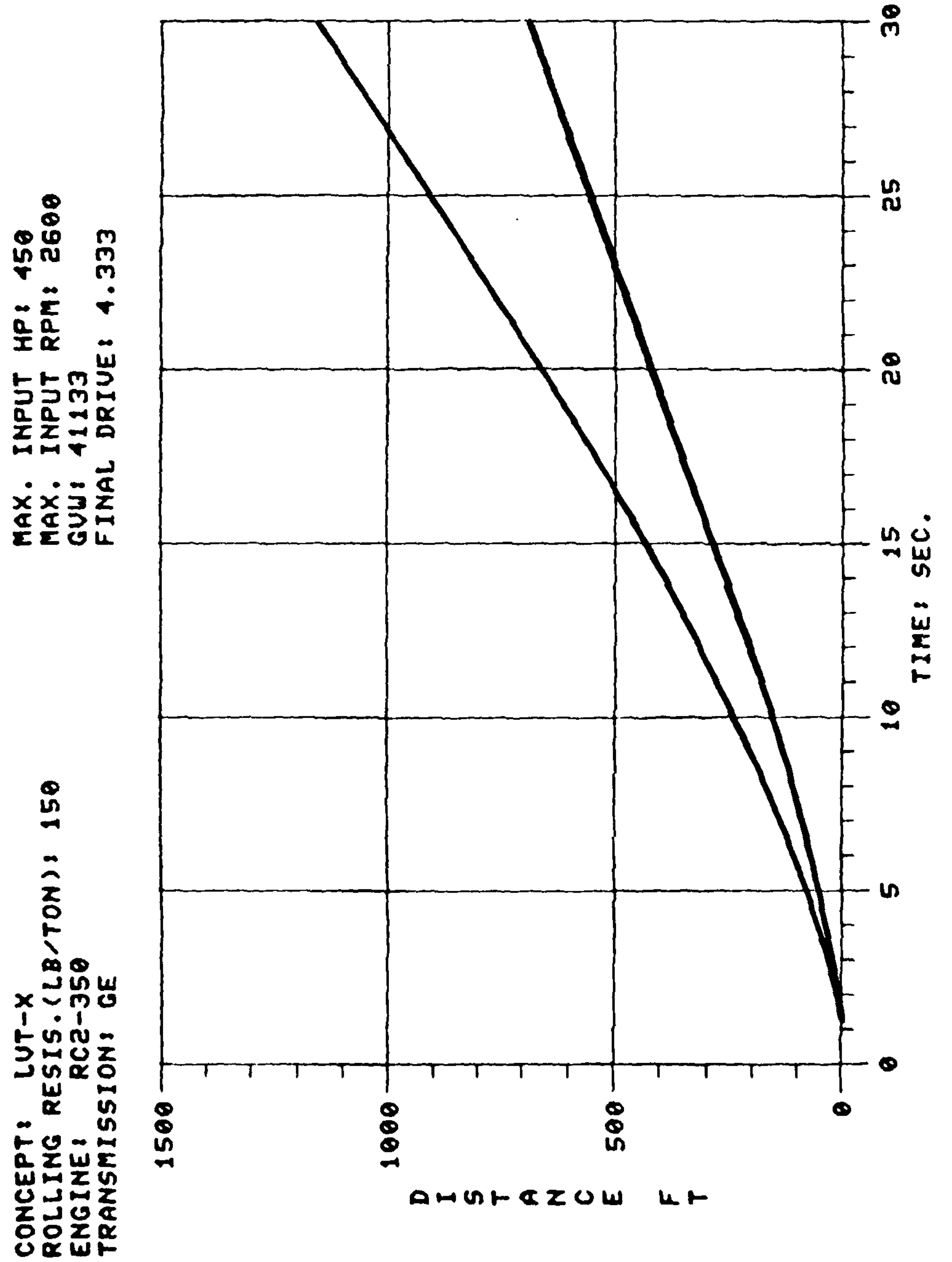

CONCEPT: LUT-X
ROLLING RESIS.(LB/TON): 150
ENGINE: RC2-350
TRANSMISSION: GE
MAX. INPUT HP: 450
MAX. INPUT RPM: 2600
GVW: 41133
FINAL DRIVE: 4.333
SPEED MPH
TIME: SEC.
0
10
20
30
40
50
5
15
25

FIGURE C-27



CONCEPT: LVT-X
ROLLING RESIS.(LB/TON): 150
ENGINE: RC2-350
TRANSMISSION: GE
MAX. INPUT HP: 450
MAX. INPUT RPM: 2600
GVW: 41133
FINAL DRIVE: 4.333
DISTANCE FT
1500
1000
500
0
0
5
10
15
20
25
30
TIME: SEC.

FIGURE C-28

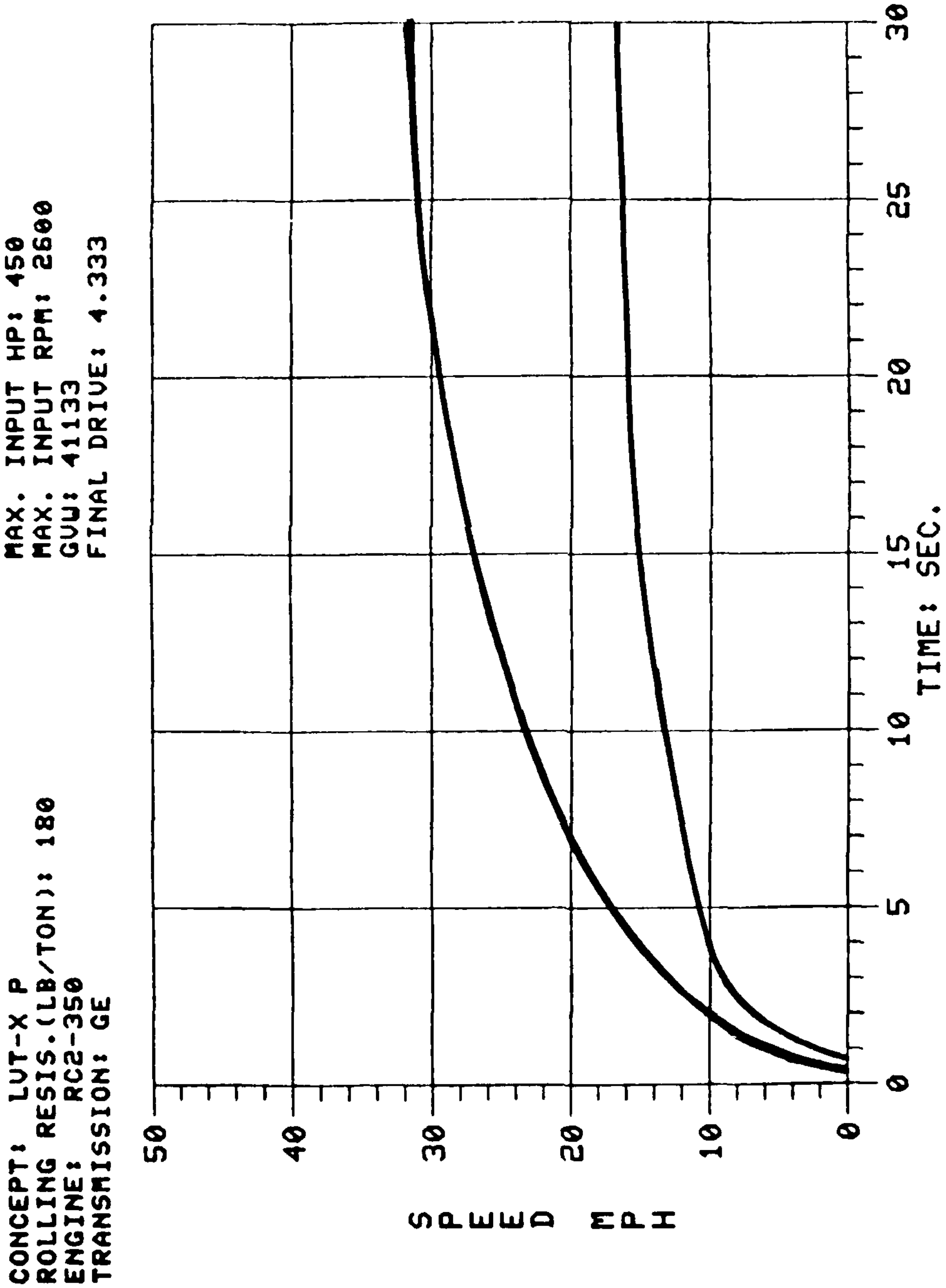

CONCEPT: LVT-X P
ROLLING RESIS.(LB/TON): 180
ENGINE: RC2-350
TRANSMISSION: GE
MAX. INPUT HP: 450
MAX. INPUT RPM: 2600
GVW: 41133
FINAL DRIVE: 4.333
SPEED MPH
0
10
20
30
40
50
TIME: SEC.
0
5
10
15
20
25
30

FIGURE C-29

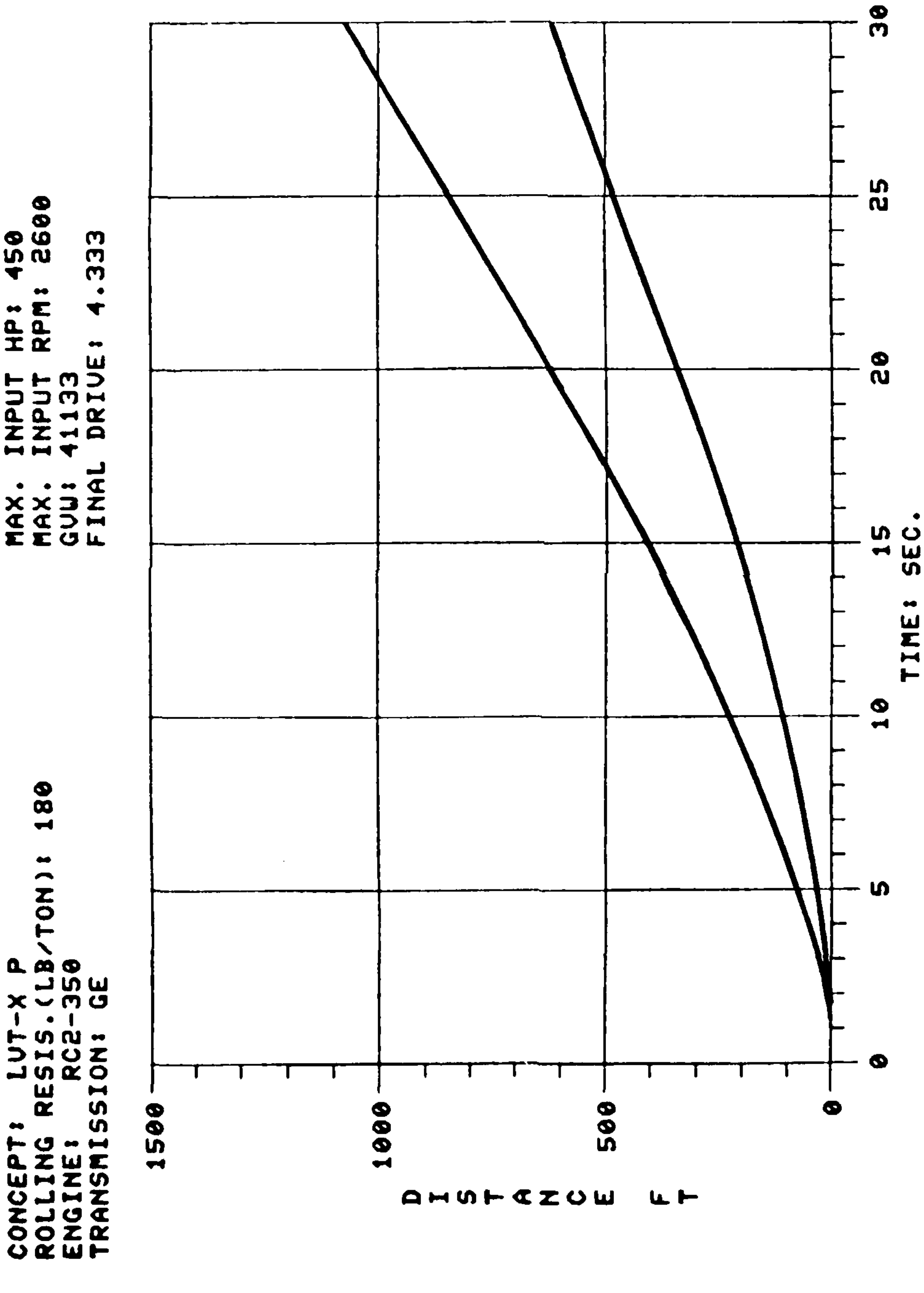
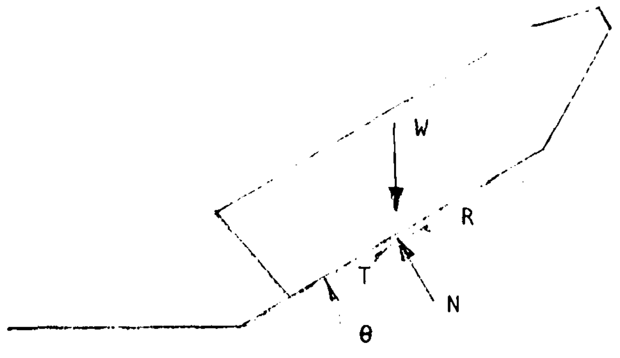

CONCEPT: LUT-X P
ROLLING RESIS.(LB/TON): 180
ENGINE: RC2-350
TRANSMISSION: GE
MAX. INPUT HP: 450
MAX. INPUT RPM: 2600
GVW: 41133
FINAL DRIVE: 4.333
DISTANCE FT
1500
1000
500
0
0
5
10
15
20
25
30
TIME: SEC.

FIGURE C-30

APPENDIX D

SOFT SOIL -- NATURAL OBSTACLE CROSSING ANALYSIS



TRACTIVE FORCE

T = Force required = R + W sin θ

R = Soil motion resistance = RTOW * N

W = Weight

θ = Slope angle

N = Normal force = W cos θ

RTOW = Resistance to weight ratio

Available from Soil = A * c + N * tan Ø

c = Soil cohesion

Ø = Soil friction angle

A = Area of support on ground

The area of support depends on vehicle and obstacle geometry. For this analysis, it is assumed to be as large as possible, i.e., the smaller of 2 * TL * WID and 2 * BL * WID where:

WID = Width of one track

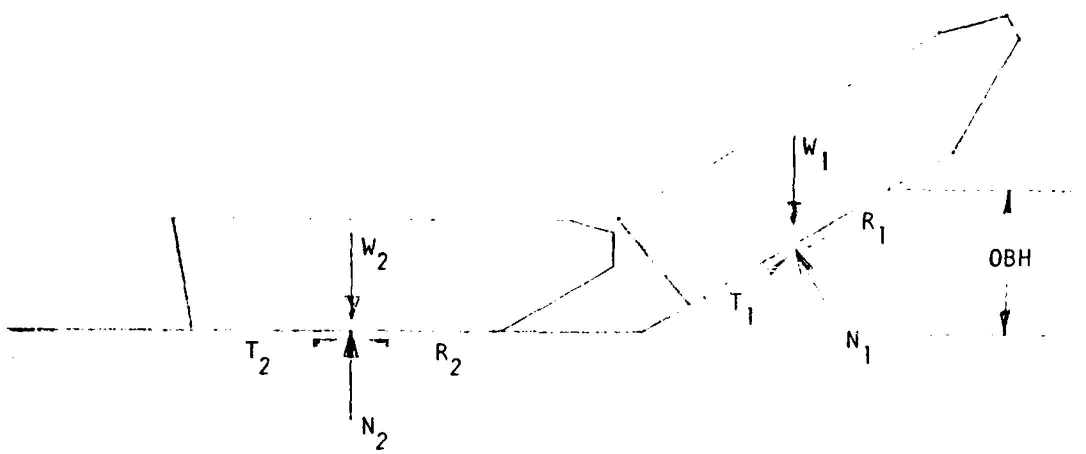
TL = Length of the track on the ground

BL = Banklength = OBH/sin θ

OBH = Obstacle height

One should note that in the case of the single unit, the forces required are completely determined in equilibrium.

With coupled vehicles, the first unit can be in this critical position while the second unit still has capacity to assist. (Of course, if the obstacle is large enough to contain the entire coupled combination, the same immobilization will occur.) This situation is pictured below:



In studying this situation, we first considered those obstacles which had been indicated as NO-GO's in the LVA Scenario I for the P-7. We found that the geometry of the coupled P-7's is such that the center of gravity would be over the crest, i.e., the size and ability to conform to the ground, allow the first unit to attain the top of those mounds with relative ease. (These mounds were about three (3) feet high.)

We then looked at obstacles which are large enough to support a single unit on their slope. (As noted before, if both units fit on the slope immobilization is not affected by coupling. The gain is in those intermediate in size.) Unlike the case of the single unit where the desired forces (tractive and normal) are determined by the equilibrium equation, we now must obtain four (4) forces and have only three (3) equations from equilibrium.

To obtain a fourth relationship, we restricted the study to the extreme soil types, purely frictional soil (sand), and purely cohesive soil (clay). In general, the tractive force available from the soil is a linear combination of the contact area (A) and the normal load (N),

$$\text{Tractive force available} = A * c + N \tan \phi,$$

where c and ϕ are the soil descriptors. In the case of frictional soil (c = 0) it is assumed that the tractive forces on the first and second units will be proportional to the respective normal forces, i.e., $T_1 = kN_1$ and $T_2 = kN_2$. Then the tractive force is available from the soil if $k \leq \tan \phi$. For cohesive soil ($\phi = 0$) the assumption is that the tractive forces will be proportional to the area, $T_1 = kA$, and $T_2 = kA_2$. In this case the force is available from the soil if $k \leq c$.

The result of the analysis is, for a given soil and obstacle height, the limiting obstacle approach angle for traction of the vehicle in this specified critical position. The difference for the single and coupled vehicle provides an indication of the capability of the second unit to provide assistance in obstacle climbing. It is, however, merely a "snap-shot" of one position in the entire traversal. For the table below, an obstacle height of 200 inches was arbitrarily chosen.

SOIL TYPE		LIMITING SLOPE SINGLE	COUPLED
Cohesive	c = 3 psi	14.0	28.5
	c = 4 psi	23.5	46.5
Frictional	$\phi = 20^{\circ}$	15.5	31.0
	$\phi = 25^{\circ}$	21.5	45.0

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