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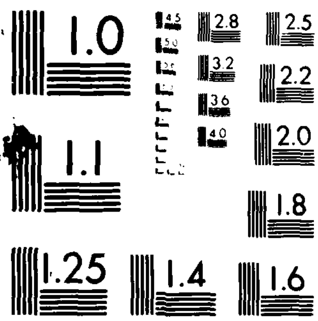

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SYSTEMS ANALYSIS OF REMOTE PILOTING/ROBOTICS TECHNOLOGY APPLICABLE TO ASSAULT RAFTS

ARTHUR D. LITTLE, INC.
ACORN PARK
CAMBRIDGE, MA 02140

JANUARY 1982

FINAL REPORT

prepared for

U.S. ARMY MOBILITY EQUIPMENT RESEARCH AND DEVELOPMENT COMMAND
FORT BELVOIR, VIRGINIA 22060

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Arthur D Little, Inc.

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This report presents the results of a technology assessment and system analysis for the application of remote control and robotics technology to military assault rafts. A number of system concepts were identified and evaluated, leading to the recommendation of a remotely piloted raft as the most promising baseline concept.

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FOREWORD

This report is submitted to the U.S. Army Mobility Equipment Research and Development Command (MERADCOM), Fort Belvoir, Virginia 22060, by Arthur D. Little, Inc., 20 Acorn Park, Cambridge, Massachusetts 02140 and was prepared under Task Order 0023 of Contract DAAK70-79-D-0036. The work was conducted under the technical guidance of Mr. Carlos Piad of MERADCOM. The Contracting Officer's Technical Representative was Mr. K. Jerry Dean of the MERADCOM Systems Analysis Division. Questions of a technical nature should be directed to Mr. John S. Howland (617) 864-5770, the Manager of the Program and Principal Investigator. The Administrative Program Manager was Mr. Roger G. Long, who also served on the technical program team. Other investigators included Mr. Robert H. Bode, Dr. E. George Pollak, and Mr. Richard H. Spencer.

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1. SUMMARY

1.1 INTRODUCTION

The United States Army desires to improve its wet-gap assault rafting equipment for the period beyond 1985. This report presents the results of a technology base assessment and system analysis for the application of remote and automatic control technology to military assault rafts.

1.2 BACKGROUND

Modern river crossing techniques stress rapid wet-gap crossing in stride without loss of momentum. For armored units, this suggests the value of a system that would permit crossing by personnel organic to the armored unit under conditions of light resistance before the initial tanks have eliminated enemy troops from the far shore. Conventional or planned rafting or bridging equipment requires time to assemble and deploy the engineer support personnel and equipment. On-board raft operators are then vulnerable to enemy fire.

The Remotely Piloted Assault Raft (RPAR) concept was conceived to overcome these problems and provide a more responsive system.

1.3 OBJECTIVE

The overall objective of this task was to evaluate the feasibility of the RPAR concept. The objectives of the individual studies leading to this overall objective were to:

- Define the most promising baseline system concept for the RPAR,
- Assemble a technology base for the concept, and
- Consider the military worth of the concept.

1.4 SCOPE OF WORK

The task was dividied into five major subtask areas as follows:

(1) Technology assessment and conceptual design for the overall system (Section 2.0) and each of the major subsystems. (Section 4.0)

(2) Identification of vehicle characteristics for the principal vehicles to be transported by the RPAR (Section 3.0)

(3) Definition of the most promising baseline concept for the system and assessment of its feasibility (Section 5.0)

(4) Preliminary cost estimate for the RPAR system (Section 6.0)

(5) Analysis of military worth (Section 7.0)

1.5 FINDINGS

The principal findings of the major subtask areas are summarized in Sections 1.5.1 through 1.5.5 that follow.

1.5.1 Conceptual Design and Technology Assessment

(a) System considerations show that the essence of the RPAR system is embodied in the method of control selected. Of a variety of possible control approaches, only two were found to be promising:

(1) Remotely piloted manual control of the raft for both passages.

(2) Forward passage control by the vehicle commander with automatic return by homing.

(b) The raft hull can closely follow the existing technology base provided by existing or planned military bridging and rafts.

(c) To maximize transportability, the raft should be modularized to use one hull section for loads up to MLC-35 and two connected sections for loads up to MLC-70.

(d) Propulsion can best be provided by two 360° rotatable thrusters mounted flush with the bottom of the hull in the center compartment of each module. These thrusters must be of the pump jet type and should be driven by air-cooled diesel engines.

(e) The on-board controller is the heart of either control approach given in (a) above. It combines the functions of a special purpose computer and signal processor to translate command signals into appropriate thruster control signals as well as other control functions.

(f) The primary navigational feedback information for a remote pilot will be his vision. However, in poor visibility or at night, feedback can best be provided by short-range radar combined with telemetered directional gyro information.

(g) Far shore docking guidance can be provided to the remote pilot by the vehicle commander. Alternatively, the latter could take over direct control for the docking phase.

(h) The optimum method of providing the command and navigational channels between the raft and remote pilot is digital data transmission via short-range inductive signaling on a carrier below 20 kHz.

1.5.2 Vehicle Studies

(a) The vehicles most likely to use the RPAR in the conduct of tactical missions are armored personnel carriers, and possibly self-propelled guns, howitzers, anti-aircraft guns, and surface-to-air missiles.

(b) The weight range the raft will have to support under routine conditions is from slightly greater than 3 short tons (ST) to as high as 70 ST.

(c) The mobility of the vehicles ranges from one meter fording capability to fully amphibious. The climbing capability is approximately 60% for all vehicles, and the side slip capability ranges from 30 to 40%.

(d) Under buttoned-up conditions, the tank commander typically has the best vision capability of the crew and therefore would have the greatest control and communications capability. The driver of an M-1 tank, for example, has a view which is limited to $\pm$ 50° to 75° in the horizontal plane with limited vertical vision capability of 8° to 11°, all below the horizon.

(e) The track, or wheel, interface with the RPAR ranges in width from 1.6 meters (m) to 3.7 m, and the wheel base, or track length on the ground ranges from 2.3 m to 5.0 m.

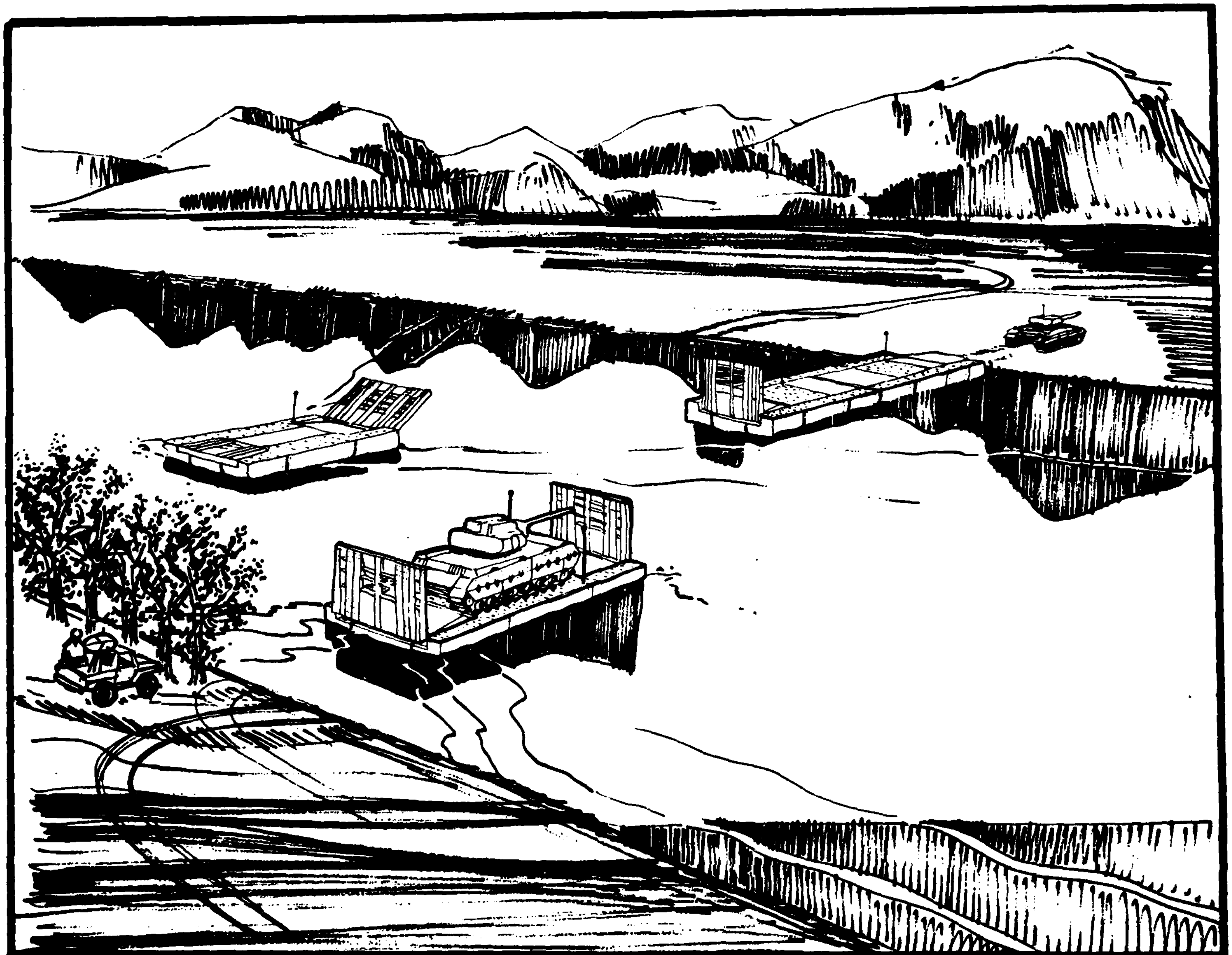
1.5.3 Baseline Concept and Feasibility

(a) The most promising baseline system control approach was found to be the remote pilot for both forward and return passages.

(b) The baseline concepts for each major subsystem were selected as summarized in Table 1. An artist's rendition of the baseline RPAR system in operation is shown in Figure 1. A single RPAR module transporting a light armored vehicle is shown in Figure 2.

TABLE 1. BASELINE RPAR SYSTEM

- 2 hull sections (one for M-3, two for M-1)
- 2 jet-type propulsors per section
- On-board data processor
- Remote control by near-shore pilot with dual capability on vehicle and raft
- Voice link with vehicle
- Navigational information by radar and telemetered from on-board directional gyro
- Tank commander directs far-shore docking by voice or dual control box
- On-board processor automatically holds raft on shore (auto pilot function)
- Return to near-shore by near-shore pilot



FIGIRE 1. REMOTELY PILOTED ASSAULT RAFTS IN OPERATION

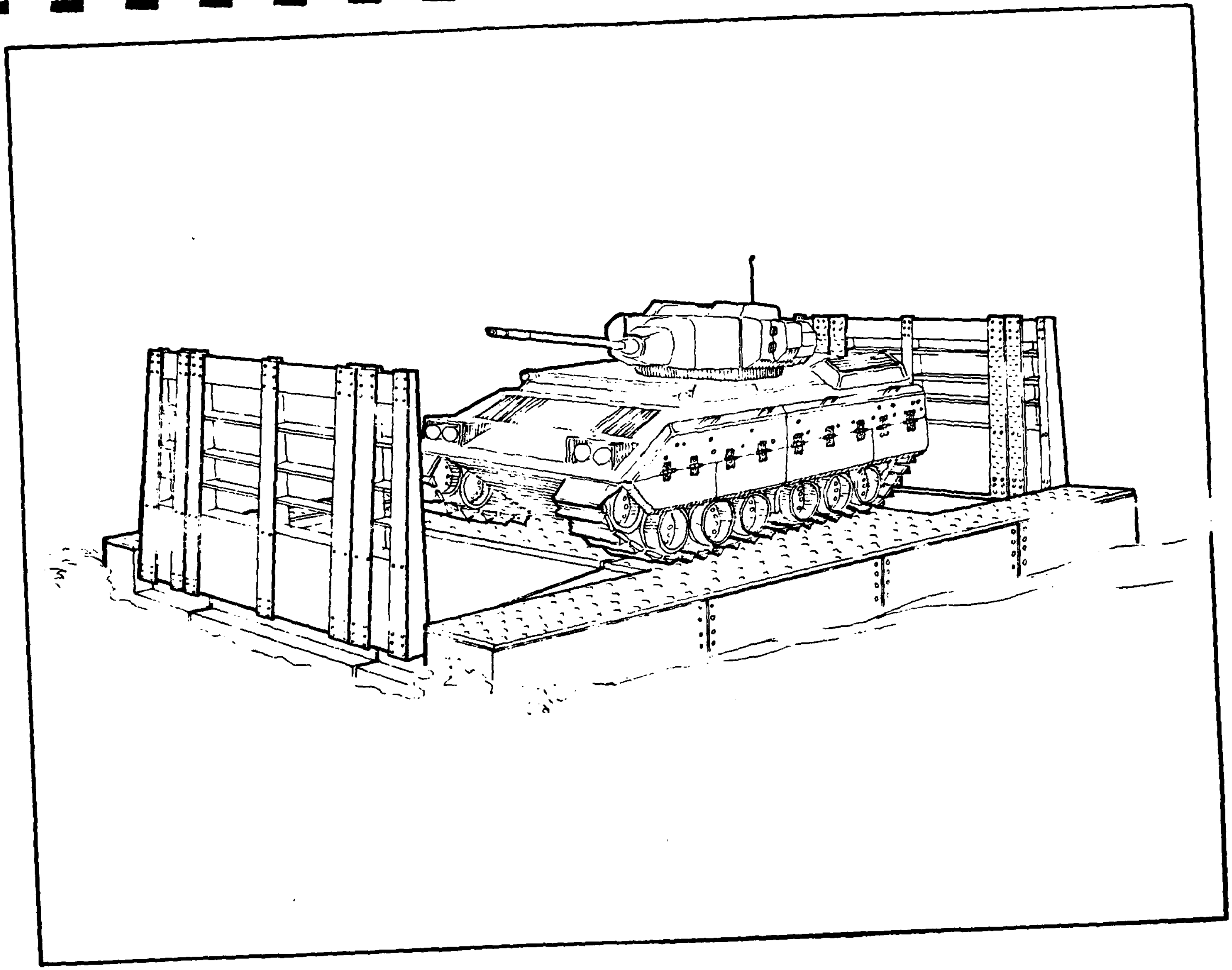


FIGURE 2. AN RPAR MODULE TRANSPORTING A LIGHT ARMORED VEHICLE

(c) There are no significant feasibility questions regarding the hardware required to implement RPAR subsystems. The RPAR subsystems may use available commercial hardware or designs similar to existing military hardware. Special purpose control and communications hardware is needed but, in each case it is well within the current state-of-the-art.

(d) The major risks identified with the development of the RPAR concern operational factors associated with the guidance and control of the craft, especially under poor visibility conditions or under stringent local conditions such as high river currents or unfavorable shore conditions. These are factors, that ultimately, will require experimental investigation; for example, with a full-scale or small-scale test bed.

1.5.4 RPAR System Cost Estimate

(a) The R&D costs to develop and produce one prototype MLC-70 RPAR system, ready for Government testing are estimated to be $2,655,000. This breaks down to $1,500,000 for the electronic command and control systems and $1,155,000 for the mechanical systems. Of this total, an estimated $1,525,000 is for preliminary design and experimental work and $1,130,000 is for developing and producing the prototype system.

(b) Acquisition costs for the system in lots of five are estimated to ultimately be $618,000 (1982 dollars) per MLC-70 system. The major components are $213,900 for one MLC-35 module, $80,000 for a trailer carrier, and $29,900 for the remote pilot station electronics.

(c) The ultimate cost of the system in high production, is projected to be reduced by up to 37% because of the combination of learning curve reductions and tooling investment. This represents a production cost of about $390,000 per system in quantity production.

1.5.5 Military Worth

(a) The military worth of organic, self-powered, quickly deployable assault rafts appears considerable for the rapid river crossings needed to implement the doctrine to be applied in future conflicts.

(b) The relative increase in military worth provided by enhancing the basic assault raft concept through the remote piloting feature is not as great as the initial step from existing river crossing methods. It is, however, believed to be significant in three respects:

(1) The RPAR concept provides rapid crossing capability at night, in dense fog, or under heavy smoke screen. This is a capability not available in any other way.

(2) The RPAR concept minimizes or eliminates the vulnerability of support personnel to enemy fire under the rapid crossing doctrine where light enemy resistance can be expected.

(3) The absence of an on-board operator reduces the need for protective armor and is expected to lighten the raft module by 1.5 ST, thus enhancing its transportability.

1.6 CONCLUSION

The basic RPAR concept is practicable and offers considerable potential worth for rapid river crossings. It can be implemented in at least two promising control modes, but the most promising is complete control by a remote human pilot with navigational aids for poor visibility conditions. All subsystems are feasible and can be implemented with available equipment or designs well within the current state-of-the-art.

1.7 RECOMMENDATIONS

The RPAR concept is recommmended as a promising [illegible] crossing system to be developed further, with an eye toward the [illegible] requirements of the 1990's and beyond.

Since the major questions appear to be concerned with operational and control factors and must, of necessity, involve the human factors interface, the initial investigations should logically be experimental. Thus, we recommend that further technology base (6.2) work should initially be directed toward the design, fabrication, and testing of a prototype to serve as a test bed for RPAR subsystems.

2. SYSTEM DESCRIPTION OF THE RPAR CONCEPT

2.1 INTRODUCTION

This section presents a general description of the RPAR concept along with the tactical situation in which it is expected to be used.

A general concept morphology is then presented to serve as a framework for the more detailed discussion of component technology covered in subsequent sections.

2.2 TACTICAL SITUATION

River crossing operations have always been an important component of land warfare. With the advent of modern armored and highly mobile forces, a significant military bridging and rafting technology has developed in order to handle water obstacles.

The objective of any river crossing is to project combat power across a water obstacle while ensuring integrity and momentum of the force.* Because of the rapid movements of forces expected in future conflicts involving conventional forces, the preservation of momentum has been greatly stressed in the development of river crossing doctrine. Field Manual FM 90-13, for example, states that all efforts must be directed ed toward crossing without loss of momentum. Only as a last resort will the force pause to build up combat power and equipment.

This doctrine is reflected in the detailed concepts defined for crossing a wet-gap obstacle. Two types of crossings are identified:

*U.S. Army Field Manual No. 90-13, "River Crossing Operations," Dept. of the Army, Washington, D.C., Nov. 1, 1978.

(a) Hasty Crossings where the force crosses in stride, using local materials and organic equipment, and

(b) Deliberate Crossings where a deliberate pause is made to centralize command of the crossing, acquire additional bridging equipment, and clear enemy resistance from the far bank of the gap.

This study is concerned only with hasty river crossings, which are the desirable mode whenever possible. In order for a hasty crossing to succeed and to avoid the need for the more-time-consuming deliberate crossing, the necessary crossing equipment must be organic to, or move closely with, the armored units. It must be capable of transporting the armored equipment across the wet gap under light enemy resistance in order to preclude time-consuming enemy clearing operations.

This is the tactical situation associated with the RPAR concept.

2.3 RPAR CONCEPT

The RPAR is envisioned as an unsinkable ferry with integral propulsion and remote piloting, automatic control, or robotic (preprogrammed) control.

The concept of self-propelled rafts or ferries has been recently studied as a method for avoiding the dependence of bridging operations on the availability of powered boats.* However, conventional bridge or raft sections would still require raft commanders and operators to be on board the rafts under enemy resistance.

*Arthur D. Little, Inc., "Definition of an Improved Wet Support Bridge Concept and Related System Analysis," Report to MERADCOM, Contract DAAK-70-79-D-0036, Task Order No. 0019, October 1981.

The RPAR concept would eliminate the vulnerable on-board raft operators. The raft would be piloted by a remote operator or by personnel inside the armored vehicle being transported. The raft would be returned to the near shore by a fixed remote operator or by an automatic control system. Thus, the operator would never be exposed to light enemy fire which is capable of penetrating the armored vehicle.

Because the RPAR system would not require separate boats and extensive operational personnel, it is envisioned that RPAR units could travel with armored units as an organic part of the force. The raft units could be towed as trailers by armored vehicles or engineer support vehicles.

2.4 CONCEPT MORPHOLOGY

The overall RPAR concept consists of several major subsystems. These include:

(a) Hull
(b) Propulsion
(c) Control System
(d) Navigational System
(e) Communications
(f) Ground Transportation System

While each of these subsystems has several alternative subsystem concepts and combinations of component concepts, it is useful to recognize at the outset that the hull, propulsion, and ground transportation systems are essentially independent of the control, navigational, and communications subsystems. This is certainly true on the concept level where, for example, it is not useful to describe the details of the interface between the propulsion system and the on-board part of the control system.

On the other hand, the control, navigational, and communication systems are closely related to one another. Moreover, the selection and description of the general control concept defines, in essence, the entire RPAR.

A morphological chart of general control concepts is shown in Figure 3. These logically group into two overall classes as shown. Thus, it can be seen that automatic control concepts and manual control using a pilot not located on the transported vehicle can be used for both forward and return passages of the raft.

On the other hand, if an operator on the vehicle being transported is used for either navigational or control functions, this mode of operation will be applicable only to the forward passage, and one of the other concepts must be used for the return passage.

2.4.1 Automatic Control Concepts

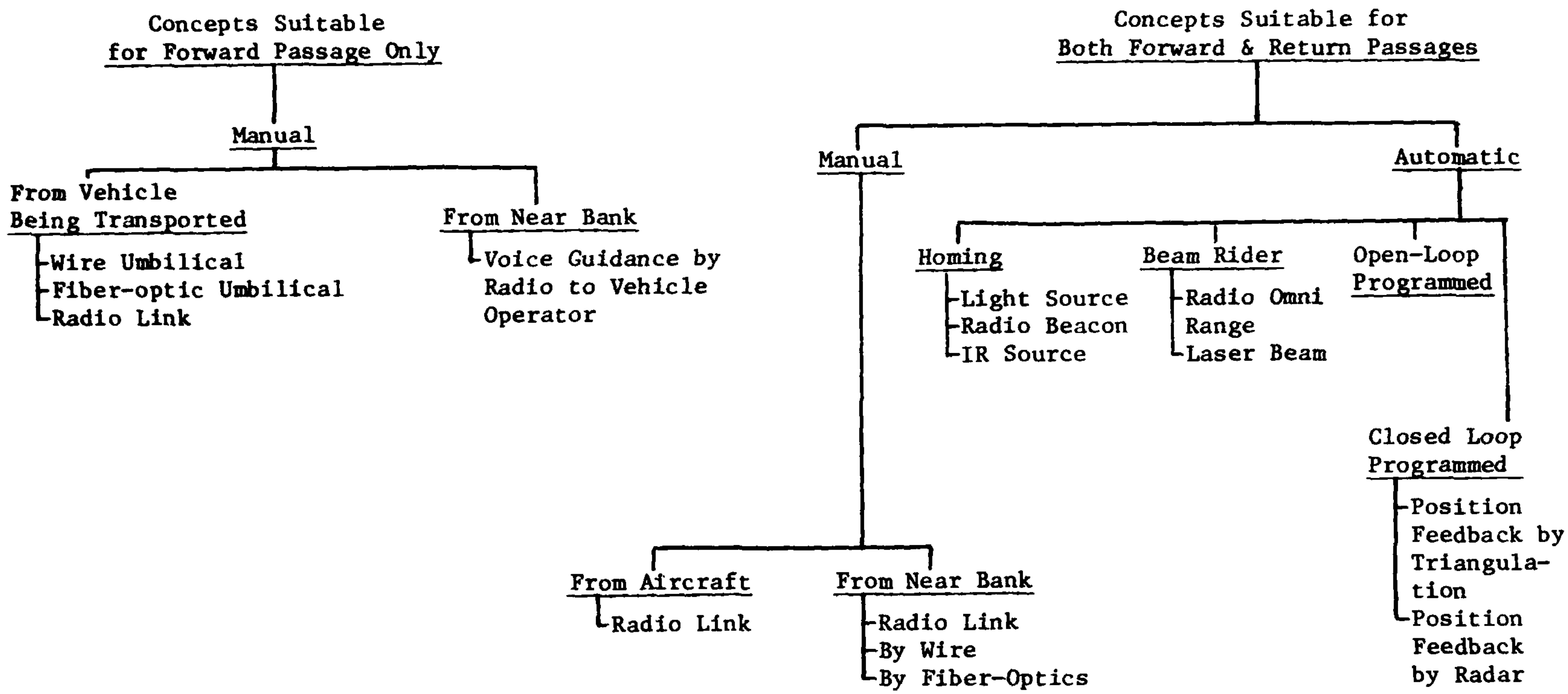
As shown in Figure 3, automatic raft control concepts can be grouped in four general subclasses:

(a) Homing - in which the control system controls the raft propulsion and heading to continuously home on a beacon or reflector that has been placed on the objective bank.

(b) Beam Rider - in which the control system controls the raft to move outward along a beam set up by a signal source on the departure bank.

(c) Open-Loop Programmed - in which the control system is pre-pro-programmed to perform a sequence of thrust level and direction changes designed to move the raft from the departure point to the target point.

FIGURE 3. CONCEPT MORPHOLOGY FOR RPAR CONTROL AND NAVIGATION



(d) Closed-Loop Programmed - in which a navigational surveillance system is used to monitor the exact location of the raft and the control system performs thrust level and direction changes to cause the raft to move along a desired path programmed into the system.

2.4.2 Manual Control Concepts

Manual control, of course, implies a human operator to change thrust level and direction. The variations among the various manual systems in Figure 3 simply describe the location of the operator and the communication methods used to effect the thrust charges.

Implicit in this concept breakdown is the condition that the manual operator has some method of feedback to tell him where the raft is located and the effect of any thrust adjustments. The simplest method to achieve this function is, of course, visual. However, at night or under poor visibility conditions, a navigational surveillance system could be used to augment the operator's vision.

For the forward passage, where a human operator is available on the vehicle being transported, this on-board operator can control the raft through a short communications link. This, of course, presumes that the operator's visibility is sufficient to pilot the raft. If this is not the case, he can be conned by pilot on the near bank through a voice link, continuing to control the thrust through a short on-board communications link.

2.5 PRELIMINARY SCREENING OF CONTROL CONCEPTS

The first stage of evaluation of the RPAR control concepts can be accomplished by comparison of their general functional characteristics and capabilities.

2.5.1 Automatic Control Concepts

Automatic control concepts, as a class, can be characterized as relatively inflexible in adapting to changing or non-ideal field conditions. For example, where a manual operator can detect obstacles and perform an evasive maneuver, the automatic system without considerable increased complexity cannot. A human operator can detect wind or current changes and adjust thrust accordingly, but several automatic concepts would have difficulty adjusting to these changes. In particular, the subclasses of Figure 3 can be expected to have the major characteristics described in (a) through (d) below.

(a) Homing

Homing systems require that a beacon or reflector be placed on the far shore. In advance of the first passage, this requires the crossing of the river by an advanced party, probably in a portable boat. This is not a major disadvantage since the crossing area would likely be scouted in any event. However, an emplaced radio beacon would provide the enemy with a target which, depending upon its range, could be a serious disadvantage.

Visible light and, to a lesser extent, infra-red beacons are susceptible to poor visibility, weather conditions, and interference or confusion from other light or heat sources. Radio beacons, while effective in all visibility situations, are susceptible to enemy interference.

The principal advantage of a homing device is that it provides a very simple automatic navigational/control system that, given enough engine power, will lead the raft to the aim point.

However, in a river with a substantial current, the path taken by the raft may not be optimum as shown in the schematic diagram of Figure 4(a). In some cases, of high current velocity, this could lead to an inability to reach the target. Adding the complexity of manually setting in an upstream thrust vector component in advance of the crossing could produce a characteristic such as shown in Figure 4(b).

(b) Beam Rider

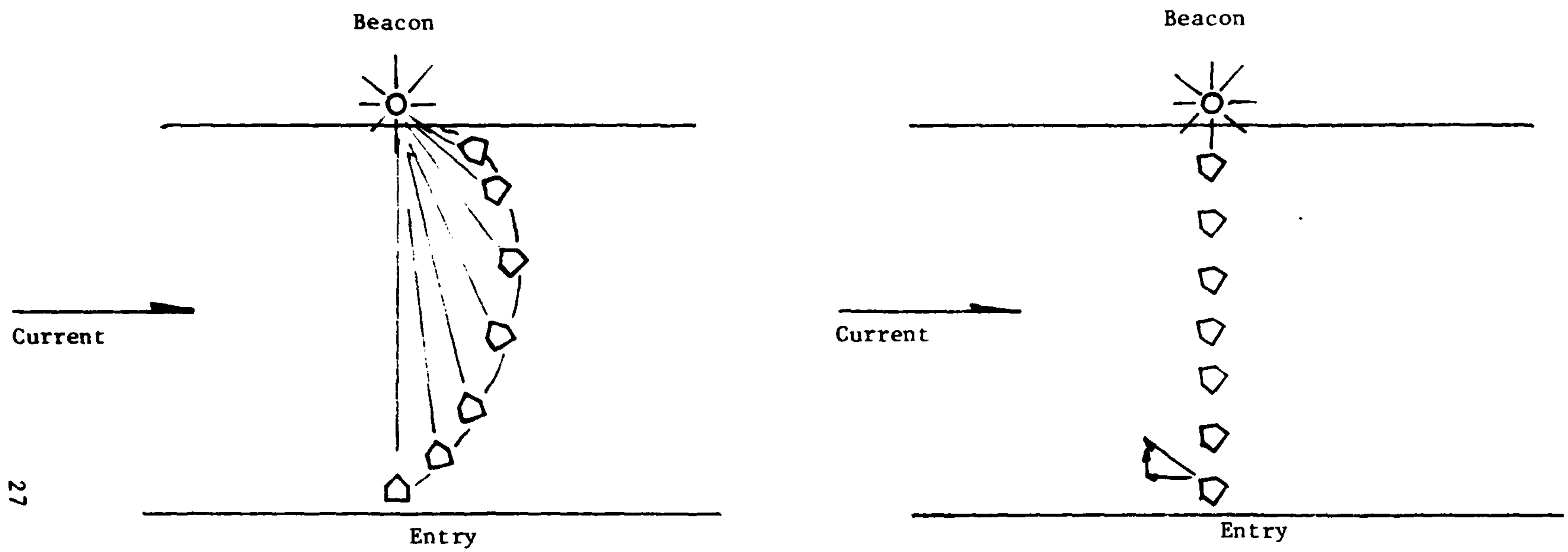
A vehicle cannot ride a beam from a non-directional beacon outbound without experiencing a constantly increasing error from the desired directional path. Thus, beam riding is constrained to coherent or narrow beams of energy like the aircraft omni range or a laser beam. Again, light is susceptible to poor transmission conditions. A narrow beam radio range of this type requires a complex antenna installation and is not consistent with rapid deployment in the field. Thus, outward beam riding is not felt to be a promising approach.

(c) Open-Loop Programmed Path

This method of control, widely used in machine processes made up of relatively rigid linkages, suffers from the major disadvantage that it is entirely incapable of accommodating spurious environmental variations. For example, wind shaft or unforeseen engine thrust changes would result in a totally different raft trajectory from the programmed sequence of control steps. Thus, this concept is not felt to be promising.

(d) Closed-Loop Programmed Path

This concept requires the comparison of the raft trajectory with a preprogrammed path and the use of corrective thrust variations to ensure that the programmed path is followed. It requires a complex navigational surveillance feedback system comparable to that required by a remotely located human pilot operating in poor visibility conditions. However, it also requires a complex control device, probably a computer, to per-



(a) Homing with Forward Thrust

(b) Homing with Upstream Thrust Bias

FIGURE 4. SCHEMATIC DIAGRAM OF HOMING SYSTEM TRAJECTORIES

form the logic operations required to decide upon the appropriate corrective maneuvers.

At the outset of the crossing for a given river, the desired path would have to be programmed into the controller. Rapid accomplishment in the field would require an interactive terminal such as a graphical display with a light pen input. This type of technology is readily available, but expensive if provided with each raft.

While this is certainly a feasible approach, its major potential advantage would be the elimination of one remote pilot. Since there would be a need to provide a human pilot for programming and to back up the automatic system, the advantage is dubious.

2.5.2 Manual Control Concepts

(a) Method of Communication

A human pilot must have the capability of making thrust level and direction changes through an on-board thrust controller. If this pilot is located on the shore of the river, the use of a hard wire or fiber-optic cable would require a long, vulnerable and unwielding cable which would be extremely undesirable. Cable handling, payout and retrieval would require special, bulk equipment. Although a hard wire cable system would be extremely resistant to enemy interference, the disadvantages would appear to be prohibitive. For a human operator on the vehicle being transported, however, an umbilical cable connecting the vehicle to the RPAR hull remains a promising communication method.

(b) Pilot Location

If the only human pilot is located on the vehicle, then an automatic return passage system is required. If a human pilot is provided on the near bank, he could handle both forward and return passages, obviating the need for a complex closed-loop system or the disadvantages of a homing system. In addition, the use of a shore pilot is entirely consistent with multiple-location control. Thus, control could be relinquished to the vehicle driver or a pilot located in an aircraft, if desirable.

Thus, the use of a remote human pilot appears to offer the optimum approach in terms of flexibility and simplicity. The only disadvantages would appear to be the vulnerability of the radio link to interference on the forward passage and the requirement of a single dedicated pilot for each raft. Vulnerability to interference is minimized or avoided if control can be passed to the vehicle during forward passage. It cannot be avoided for the return passage by any control concept.

2.5.3 Promising System Concepts

The preceding discussion, based on general system characteristics, provides a basis for the distillation of the concepts of Figure 3 down to two promising candidate approaches for the control of the RPAR for forward and return passages. These are:

(a) Remotely Piloted Control - A remote human pilot would be used to control both forward and return passages with dual control capability from the transporting vehicle for the forward passage.

(b) Vehicle Control with Automatic Homing - The forward passage would be controlled from the transporting vehicle by means of an umbilical cable or short radio link and the RPAR would return to the near shore by homing on a radio beacon.

The principal relative advantages of (b) would be the elimination of a navigational and control station on the near shore, the communication of control information between the shore and the RPAR; and the human pilot on the near shore.

The relative disadvantages are the loss in flexibility for remote control, vulnerability to errors or interference with the homing system, and a more complex on-board control system.

3. VEHICLE CHARACTERISTICS

3.1 INTRODUCTION

Several types of U.S. armored vehicles were considered to be the most likely to use the RPAR as a ferry to make hasty crossings of a wet gap. These included tanks, armored personnel carriers, reconnaissance vehicles, self-propelled guns and howitzers, and self-propelled anti-aircraft guns and surface-to-air missiles. The range in weight of these vehicles is from a light reconnaissance vehicle, such as the XM966 weighing approximately 3.6 ST to M1 tank weighing approximately 58.9 ST.* We assumed that under most conditions the vehicle would be buttoned up during the crossing since the vehicle and raft could be under small arms fire as well as indirect fire. We were principally concerned with the visibility of the commander and the driver of the vehicle in the buttoned-up condition. We included amphibious vehicles since the RPAR would have the capability of transporting the amphibious vehicle across the wet gap much faster than it could proceed under its own power.

3.2 GENERAL DISCUSSION

We used the 1979-80 edition of JANE's Armour and Artillery as the basic source for vehicle characteristics. In addition, we contacted the Human Engineering Laboratory at the U.S. Army Tank-Automotive Command (USATACOM) to obtain human factors engineering analysis of available armored vehicle systems. Detailed information was obtained on the M1 tank system and on ground surface visibility summary information for both the commander's station and driver's station on the M2 personnel carrier and the M3 reconnaissance vehicle.

*The weight growth of the M-1 Tank may approach MLC-70.

The vehicle characteristics that were considered pertinent to the study for each armored vehicle type included:

- Chassis information, such as the interface information between the vehicle and the RPAR; namely, the distance in width between track, which was called track;

- The individual width of each track;

- The track length on ground;

- Weight of the armored vehicle;

- Driver position, including his location in the hull and a description of the hatch cover and the button-up vision devices;

- Command position, including his location in the vehicle or in the turret and his vision devices;

- Vision summary, which is coded for brevity; and

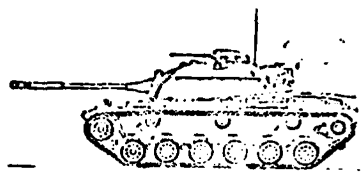
- Mobility information including fording depth, gradient capabilities, such as climbing capabilities, down or up a bank condition, and side slope capabilities.

- The final information was a line drawing of the vertical elevation of the vehicle.

This information is presented in Table 2 which devotes a page to each vehicle in the categories of tanks, armored personnel carriers, reconnaissance vehicles, self-propelled guns and howitzers, and self-propelled anti-aircraft guns, and surface-to-air missiles.

TABLE 2. ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Tanks	M48A5



Chassis Interface Data	Weight
M48 T 2.981 m	47,180 kg
TW 711 mm	52.0 ST
TLOG 4.999 m	

Driver Position

Driver seated at front of hull in the center - single piece hatch cover - 3 M27 periscopes - center periscope replaced by M25 infrared periscope for night driving.

Commander Position

Commander seated in turret at right - has an M1 cupola that can be traversed by hand through 360° - 5 vision blocks and an M28 C sight.

Vision Data Summary

D - 3P; H - 84° to 168°
V - 11° to 22°
C - 5VB; H - 200° to 360° w/crane
V - 12° to 24°

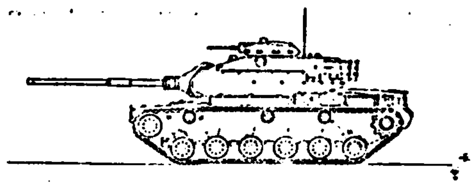
Mobility Information

F - 1.219 m (2 Prep. 2.438 m)
G - 60%; SS - ?

T = Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW = Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision Block	V = Vertical	SS = Side Slope

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Tanks	M60/M60A1 M60A2/A3



Chassis Interface Data	Weight
M60 T 2.348 m TW 711 mm TLOG 4.235 m	51,982 kg 57.3 ST

Driver Position

Driver seated front of vehicle - single piece hatch cover - 3 M27 periscopes M24 can be installed - will be replaced by passive night viewers.

Commander Position

Seated right of turret - has 360° cupola and 5 vision blocks for all-round observation.

Vision Data Summary

Information based upon polar plots.
D - 3VB; H - 170° with complete freedom of movement.
V - 12° to 24°
C - 5VB; H - 360° Commander addresses vision blocks from extreme angles.
V - 12° to 24°

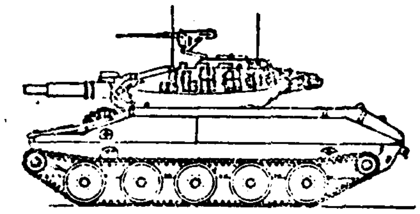
Mobility Information

F - 1.219 m (w Prep. 2.438 m, w snorkel 4.114 m)
G - 60%; SS - ?

T = Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW = Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision Block	V = Vertical	SS = Side Slope

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Tanks	M551 Light Tank



Chassis Interface Data	Weight
M551 T 2.348 m TW 444 mm TLOG 3.66 m	15,830 kg 17.5 ST

Driver Position

Driver seated at front of hull - single piece hatch cover - 3 M41 periscopes - one M48 infrared periscope replaces M47 for night driving.

Commander Position

Commander seated in turret at right - cupola with a split hatch cover - 10 vision blocks for all-round vision - portable night vision device with 4X magnification.

Vision Data Summary

D - 3P; H - 84° to 168°
V - 11° to 22°
C - 10VB; H - 360°
V - 12° to 24°

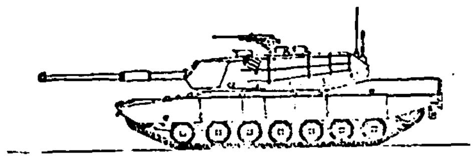
Mobility Information

F - Amphibious
G - 50%; SS - 40%

T = Track	W - Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW - Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision Block	V = Vertical	SS = Side Slope

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Tanks	M1



Chassis Interface Data	Weight
M1 W 3.655 m TW 635 mm TLOG 4.650 m	53,390 kg 58.9 ST

Driver Position

Semi-reclined position in center of chassis - single hatch opening - 3 periscopes including image intensification periscope for night driving.

Commander Position

Seated right in turret - has 6 periscopes 360°.

Vision Data Summary

D - 3VB; H - 103° to 154°
V - 8.5° to 17°
C - 6VB; H - 360°
V - 12° to 24°

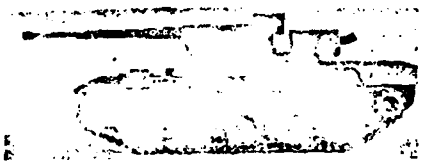
Mobility Information

F - 1.219 m (w Prep. 2.36 m)
G - 60%; SS - ?

T - Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW = Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision Block	V = Vertical	SS = Side Slope

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Tanks	HIMAG - High Mobility Agility Test Vehicle



Chassis Interface Data	Weight
HIMAG T ? TW ? TLOG ?	40,824 kg 45.0 ST

Driver Position

Driver seated at front of hull - single piece hatch cover - 3 windows for direct viewing.

Commander Position

Commander seated on side of turret - each with a single piece hatch cover - sight options include direct view by day, day video FLIR biocular, FLIR video and video information display - TTS periscope interface - integrated day/laser/FLIR.

Vision Data Summary

From the description, the driver and the commander have excellent vision. The precision of the vision is not known.

Mobility Information

F - ?
G - ?; SS - ?

T = Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW = Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision Block	V = Vertical	SS = Side Slope

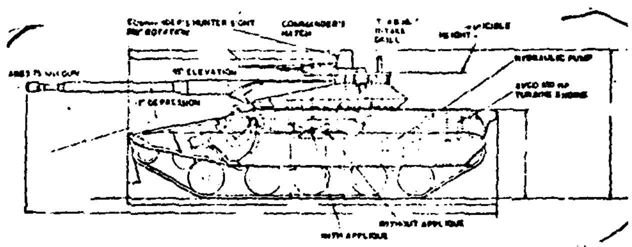
TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

<u>Vehicle Category</u>

Tanks

<u>Model</u>

HSTV (L) High Survivability Test Vehicle, Lightweight



<u>Chassis Interface Data</u>

HSTV T 2.399 m
TW 445 mm
TLOG ?

<u>Weight</u>

18,144 kg
20.0 ST

<u>Driver Position</u>

Driver seated at front of hull on left side - single piece hatch cover - 3 integral observation periscopes.

<u>Commander Position</u>

Commander seated left side of turret in the rear - single piece hatch cover - 8 periscopes for all-round observation.

<u>Vision Data Summary</u>

It is assumed that the "JANE's" reference to periscopes really means vision blocks, and the estimates are made upon the utilization of vision blocks.

D - 3VB; H - 90° to 180°
V - 24° to 48°
C - 8VB; H - 360°
V - 12° to 24°

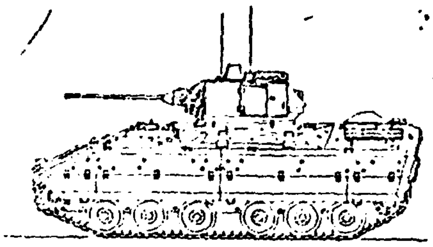
<u>Mobility Information</u>

F - 0.863 m
C - 60%; SS - 40%

T = Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW = Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision Block	V = Vertical	SS = Side Slope

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Reconnaissance	XM3 (M3)



Chassis Interface Data	Weight
M2 T 2.971 m TW 533 mm TLOG 3.911 m	21,319 kg 23.5 ST

Driver Position

Driver seated at front of hull on left side - single piece hatch cover - 4 periscopes--3 to front, one to left side. The center front periscope can be replaced by an AN/VVS - 2 passive night periscope.

Commander Position

Commander seated on right side of turret - single piece hatch cover - periscopes for front and side observation.

Vision Data Summary

The following information is directly from the US Army Tank-Automotive Command. For the driver the vertical viewing angle from the driver's 4 vision blocks ranges from 7.2° to 10.3° for the vertical viewing angle. The quantity of degrees is assumed to be doubled if the driver were capable of moving both his head and his eyes. The total unobstructed view for the driver in the horizontal is 118°. From 50° to the right to 259° to the left the vehicle hull obstructs all horizontal vision. The minimum distance that can be seen directly in front of the driver is 51 feet. For the commander, the vertical angle for his vision ranges from 7.4° to 13° for the 8 vision blocks. This information is with the commander's eyes located at the vertical center of the vision blocks. The viewing angle can be approximately doubled with head and eye movement. There are five points in which the horizon is not visible in horizontal viewing. The total unobstructed view is 297°. The minimum distance that can be seen straight ahead by the commander is 49 m.

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Reconnaissance	XM3 (M3) (Continued)

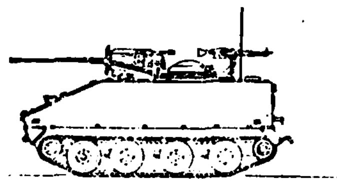
Mobility

F - Amphibious
G - 60%; SS - 40%

T = Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW = Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision Block	V = Vertical	SS = Side Slope

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Reconnaissance	M114



Chassis Interface Data	Weight
M114 T 1.912 m TW 419 mm TLOG 2.311 m	6,928 kg 7.6 ST

Driver Position

Driver seated at front of hull on left side - single piece hatch cover - integral M19 infrared periscope - 3 M26 periscopes for forward vision mounted in front of hatch.

Commander Position

Commander seated in turret with cupola - single piece hatch - 8 vision blocks that can be traversed through 360° by hand wheel at 2° of transverse per revolution of the hand wheel.

Vision Data Summary

D - 3P; H - 82.5° to 165°
V - 11° to 22°
C - 8VB; H - 320° to 360° with hand crank
V - 12° to 24°

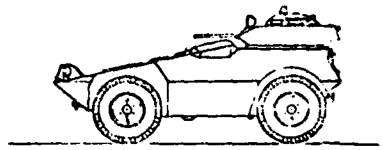
Mobility Information

F - Amphibious
G - 60%; SS - 30%

T = Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW = Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision Block	V = Vertical	SS = Side Slope

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Reconnaissance	Commando Scout 4 x 4



Chassis Interface Data	Weight
CS WW 1.651 m WB 2.661 m	6,123 kg 6.7 ST

Driver Position

Driver seated on left side of hull has adjustable seat - single piece hatch cover - a vision block in front of hatch when vehicle is driven closed down.

Commander Position

Commander or gunner can be in turret. The turret is provided with 8 vision blocks.

Vision Data Summary

Although "JANE's" refers to a single vision block in front of hatch, we expect this is an exceptional vision block to give reasonable vertical and horizontal vision to the driver. The commander has 8 vision blocks which would provide 320° to 360°.

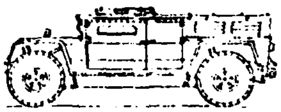
Mobility Information

F - 1.168 m
G - 60%; SS - 30%

T = Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW = Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision Block	V = Vertical	SS = Side Slope

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Reconnaissance	XM966, 4 x 4 Combat Support Vehicle



Chassis Interface Data	Weight
WW 1.63 m WB 3.07 m	3,265 kg 3.6 ST

Driver Position

Driver seated on left side of the vehicle - vehicle has conventional windshield--single piece or two piece.

Commander Position

Gunner is seated on the right side of the vehicle - seat can be adjusted to a high vantage position for surveillance - seat is folded vertically to permit gunner to stand when firing weapons.

Vision Data Summary

The driver has a conventional windshield. With eye and head movement, the windshield should present 150°+ of horizontal vision and 60° or more of vertical vision. The commander position is not described, only the gunner's. He is seated to the right of the driver, hence would have similar vision capabilities.

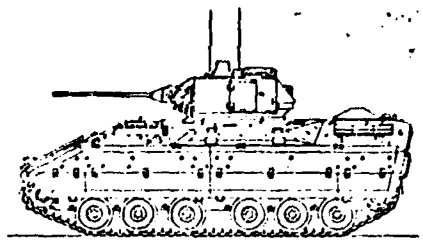
Mobility Information

F - 0.76 m
G - 60%; SS - ?

T = Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW = Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision Block	V = Vertical	SS = Side Slope

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Armored Personnel Carriers	XM2



Chassis Interface Data	Weight
M2 T 2.971 m TW 533 mm TLOG 3.911 m	21,319 kg 23.5 ST

Driver Position

Driver seated at front of hull on left side - single piece hatch cover - 4 periscopes - 3 to front, one to left side. The center front periscope can be replaced by an AN/VVS-2 passive night periscope.

Commander Position

Commander seated on right side of turret - single piece hatch cover - periscopes for front and side observation.

Vision Data Summary

The following information is directly from the US Army Tank-Automotive Command. For the driver the vertical viewing angle from the driver's 4 vision blocks ranges from 7.2° to 10.3° for the vertical viewing angle. The quantity of degree is assumed to be doubled if the driver were capable of moving both his head and his eyes. The total unobstructed view for the driver in the horizontal is 118°. From 50° to the right o 259° to the left the vehicle hull obstructs all horizontal vision. The minimum distance that can be seen directly in front of the driver is 51 feet. For the commander, the vertical angle for his vision ranges from 7.4° to 13° for the 8 vision blocks. This information is with the commander's eyes located at the vertical center of the vision blocks. The viewing angle can be approximately doubled with the head and eye movement. There are five points in which the horizon is not visible in

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Armored Personnel Carriers	XM2 (Continued)

horizontal viewing. The total unobstructed view is 297°. The minimum distance that can be seen straight ahead by the commander is 49 m.

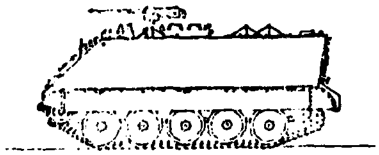
Mobility Information

F - Amphibious
G - 60%; SS - 40%

T = Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW = Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision Block	V = Vertical	SS = Side Slope

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Armored Personnel Carriers	M113, M113A1



Chassis Interface Data	Weight
M113 T 2.159 m TW 3.81 mm TLOG 2.667 m	11,156 kg 12.3 ST

Driver Position

Driver seated at front of hull on left side - single piece hatch cover - on front and left side are 4 M17 periscopes and also an M19 periscope in its roof hatch. An infrared or passive periscope can replace one of the day periscopes for driving at night.

Commander Position

Commander seated to rear of engine compartment - provided with cupola that can be traversed 360° and has 5 M17 periscopes - single piece hatch cover.

Vision Data Summary

D - 4P; H - 110° to 150°+
V - 11° to 22°
C - 5P; H - 137° to 275°
V - 360° with cupola traversing

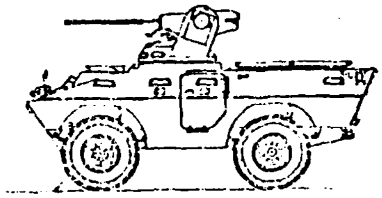
Mobility Information

F - Amphibious
G - 60%; SS - ?

T = Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW = Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision Block	V = Vertical	SS = Side Slope

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Armored Personnel Carriers	AM301, AM331, 4 x 4



Chassis Interface Data	Weight
AM301 WW 1.981 m WB 2.794 M	11,338 kg 12.5 ST

Driver Position

Driver seated at front of vehicle on left - 3 vision blocks to front - single piece hatch cover - vision blocks in sides of hull.

Commander Position

Commander seated in front on right side - one vision block to front - single piece hatch cover - turret for gunner is provided with single piece hatch cover - 7 vision blocks - one forward facing periscope.

Vision Data Summary

D - 3VB; H - 90° to 150°+
V - 8° to 16°
C - 1VB; H - 40° to 80°
V - 12° to 24°

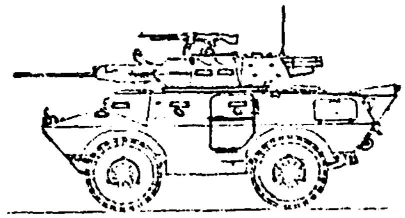
Mobility Information

F - Amphibious
G - 60%; S - 35%

T = Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW = Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision Block	V = Vertical	SS = Side Slope

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Armored Personnel Carriers	Commando V100, V150, V200 (M706), 4 x 4



Chassis Interface Data	Weight
V100 WW 1.943 m WB 2.667 m	9,888 kg 10.9 ST

Driver Position

Driver seated at front of hull on left side - 2 vision blocks in front - one vision block on left - single piece hatch cover for driver.

Commander Position

Commander sits on driver's right - one vision block to his front - one vision block to his right - single piece hatch cover. Turret can be traversed manually through 360° and has single piece hatch cover; some turrets have 8 vision blocks; there are many versions.

Vision Data Summary

D - 2VB; H - 60° to 120°
V - 8° to 16°
C - 1VB; H - 30° to 60°
V - 8° to 16°

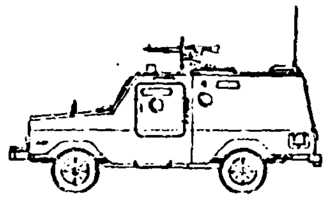
Mobility Information

F - Amphibious
G - 60%; SS - 30%

T = Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW = Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision	V = Vertical	SS = Side Slope

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Armored Personnel Carriers	Commando Ranger, 4 x 4



Chassis Interface Data	Weight
CR WW 1.663 m WB 2.641 m	4,990 kg 5.5 ST

Driver Position

Driver seated at front of vehicle on left - has a single, relatively small windshield in front and small window to left.

Commander Position

Commander seated to his right with small windshield in front and small window to right. In the troop compartment at the rear, there are two doors which have vision blocks and firing ports. One man turret with single piece hatch cover and 8 vision blocks.

Vision Data Summary

D - Has small windshield in front.
H - 90° to 150°
V - 30° to 60°
C - Has small windshield in front and small window to right.
V - Similar to driver's

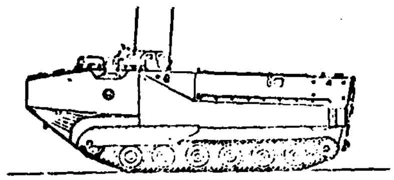
Mobility Information

F - ?
G - 60%; SS - 30%

T = Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW = Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision	V = Vertical	SS = Side Slope

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Armored Personnel Carriers	LTVP-7



Chassis Interface Data	Weight
LVTP-7 T 2.609 m TW 533 mm LTOG 3.94 m	22,838 kg 25.2 ST

Driver Position

Driver seated at front of hull on left side - single piece hatch cover - 7 vision blocks for all-round observation - M24 infrared periscope can be fitted in hatch cover for night driving.

Commander Position

Commander is seated behind driver - single piece hatch cover - 7 vision blocks for all-round observation - M17 periscope can be extended for commander to see forward over the driver's hatch cover.

Vision Data Summary

D - 7VB; H - Up to 360°
V - 12° to 24°
C - 7VB; H - Up to 360°
V - 12° to 24°

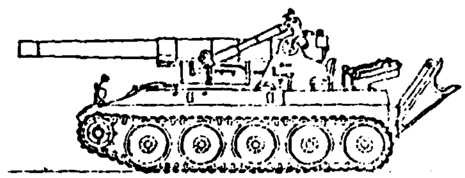
Mobility Information

F - Fully amphibious w/water jet propulsion
G - 60%; SS - 60%

T = Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW = Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision Block	V = Vertical	SS = Side Slope

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Self-Propelled Guns and Howitzers	M110 Series 8" Howitzers



Chassis Interface Data	Weight
M110 T 2.692 m TW 475 mm LTOG 3.936 m	26,534 kg 29.2 ST

Driver Position

Driver is only member of crew seated under armor - seated in front left of hull - 3 M17 periscopes - single piece hatch cover.

Vision Data Summary

D - 3P; H - 82.5° to 165°
V - 11° to 22°
C - Is not under armor; therefore has freedom of vision.

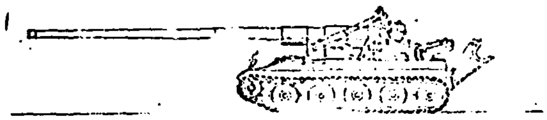
Mobility Information

F - 1.066 m
G - 60%; SS - 30%

T = Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW = Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision Block	V = Vertical	SS = Side Slope

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Self-Propelled Guns and Howitzers	M107 175 mm Gun



Chassis Interface Data	Weight
M110 T 2.692 m TW 457 mm TLOG 3.936 m	28,168 kg 31.1 ST

Driver Position

Driver is only member of crew seated under armor - seated in front left of hull - 3 M17 periscopes - single piece hatch cover.

Vision Data Summary

D - 3P; H - 82.5° to 165°
V - 11° to 22°
C - 1P; H - 27.5° to 55° with traversing 360° for horizontal vision.

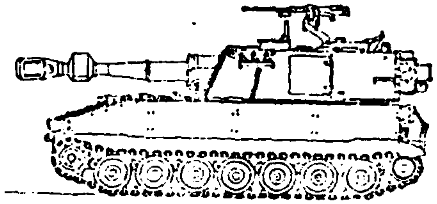
Mobility Information

F - 1.066 m
G - 60%; SS - 30%

T = Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW = Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision Block	V = Vertical	SS = Side Slope

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Self-Propelled Guns and Howitzers	M109 Series 155 mm Howitzer



Chassis Interface Data	Weight
M109 T 2.768 m TW 381 mm TLOG 3.962 m	23,786 kg 26.2 ST

Driver Position

Driver is seated in the hull to the left - single piece hatch cover - 3 M45 periscopes.

Commander Position

Commander is seated on right side of the turret and had a cupola which can traverse through 360° - a single piece hatch cover - one M27 periscope.

Vision Data Summary

D - 3P; H - 82.5° to 165°
V - 11° to 22°
C - 1P; H - 27.5° to 55° with traversing 360° for horizontal vision.

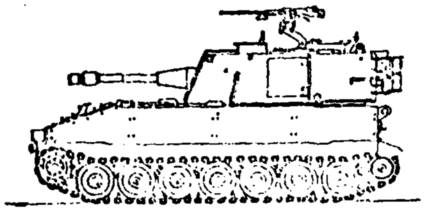
Mobility Information

F - 1.828 m
G - 60%; SS - ?

T = Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW = Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision Block	V = Vertical	SS = Side Slope

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Self-Propelled Guns and Howitzers	M108 105 mm Howitzer



Chassis Interface Data	Weight
M109 T 2.768 m TW 381 mm TLOG 3.962 m	22,452 kg 24.8 ST

Driver Position

Driver is seated in front of the hull on the left - single piece hatch cover - 3 M45 periscopes.

Commander Position

Commander is seated on the right of the turret and has a cupola which can be traversed manually through 360° - single piece hatch cover - M27 periscope.

Vision Data Summary

D - 3P; H - 82.5° to 165°
V - 11° to 22°
C - 1P; H - 27.5° to 55° with traversing 360° for horizontal vision.

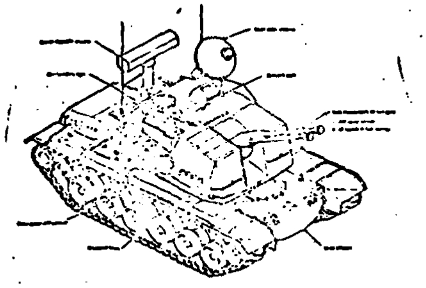
Mobility Information

F - 1.828 m
G - 60%; SS - ?

T = Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW = Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision Block	V = Vertical	SS = Side Slope

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

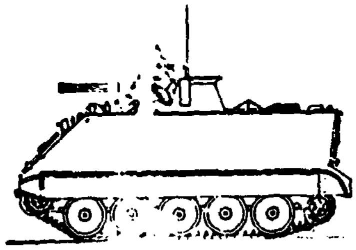
Vehicle Category	Model
Self-Propelled Anti-Aircraft Guns and Surface-to-Air Missiles	DIVADS (Div. Air Defense Gun System) Twin 40 mm



No information available; in competitive development.

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Self-Propelled Anti-Aircraft Guns and Surface-to-Air Missiles	M42



Chassis Interface Data	Weight
M27 T 2.602 m TW 533 mm TLOG ?	22,452 kg 24.8 ST

Driver Position

Driver seated at front of hull on left - single piece hatch - single M13 periscope.

Commander Position

Commander is seated in front of hull on right - single piece hatch - M13 periscope.

Vision Data Summary

D - 1P; H ~ 27.5° to 55°
V ~ 11° to 22°
C - 1P; H ~ 27.5° to 55°
V ~ 11° to 22°

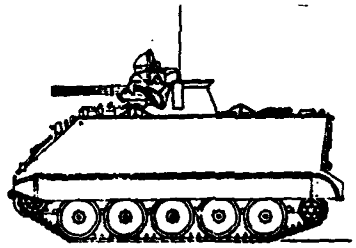
Mobility Information

F - 1.016 m
G - 60%; SS - 30%

T = Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW = Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision Block	V = Vertical	SS = Side Slope

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Self-Propelled Anti-Aircraft Guns and Surface-to-Air Missiles	M163 Vulcan Cannon 20 mm 6-Barrel



Chassis Interface Data	Weight
M741 T 2.159 m TW 381 mm TLOG 2.667 m	12,310 kg 13.6 ST

Driver Position

Driver seated at front of hull on left side - single piece hatch cover - on front and left side are 4 M17 periscopes and also an M19 periscope in its roof hatch. An infrared or passive periscope can replace one of the day periscopes for driving at night.

Commander Position

Commander seated to rear of engine compartment - provided with cupola that can be traversed 360° and has 5 M17 periscopes - single piece hatch cover.

Vision Data Summary

D - 4P; H - 110° to 150°+
V - 11° to 22°
C - 5P; H - 137° to 360° with traversing
V - 11° to 22°

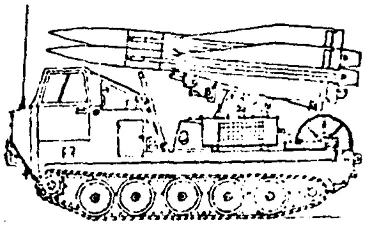
Mobility Information

F - Amphibious
G - 60%; SS - 30%

T = Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW = Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision Block	V = Vertical	SS = Side Slope

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Self-Propelled Anti-Aircraft Guns and Surface-to-Air Missiles	M727 Hawk Surface-to-Air Missile System



Chassis Interface Data	Weight
M548 T 2.159 m TW 381 mm TLOG 2.820 m	12,925 kg 14.2 ST

Driver Position

The chassis is the same as the M548 *cargo carrier* and has a full forward windshield and side windows--the same visibility as an Army truck for both the driver and commander.

Commander Position

Commander sits to the right of driver.

Vision Summary Data

D - Has same vision as from an Army truck.
C - Has same vision as from an Army Truck.

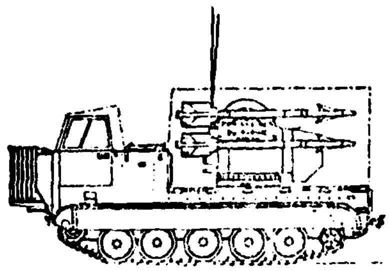
Mobility Information

F - 1.066
G - 60%; SS - 30%

T = Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW =Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision Block	V = Vertical	SS = Side Slope

TABLE 2. (CONT'D.) ARMORED VEHICLE CHARACTERISTICS AFFECTING RPAR

Vehicle Category	Model
Self-Propelled Anti-Aircraft Guns and Surface-to-Air Missiles	Chaparral Surface-to-Air Missile System



Chassis Interface Data	Weight
M548 T 2.159 m TW 381 mm TLOG 2.820 m	12,600 kg 13.9 ST

Driver Position

The chassis is the same as the M548 cargo carrier and has a full forward windshield and side windows--the same visibility as an Army truck for both the driver and commander.

Vision Data Summary

D - Has same vision as from an Army truck.
C - Has same vision as from an Army truck.

Mobility Information

F - 1.066 w/prep amphibious
G - 60%; SS - 30%

T = Track	W = Width	D = Driver	C = Commander	F = Fording
TW = Track Width	WW = Wheel Width	P = Periscope	H = Horizontal	G = Gradient
TLOG = Track Length on Ground	WB = Wheel Base	VB = Vision Block	V = Vertical	SS = Side Slope

3.3 CRITIQUE ON DRIVER AND COMMANDER STATIONS

The most complete information package on the positions of a driver and the positions of a commander in their respective stations was presented in a reported dated 10 January 1979, "Human Factors Engineering Analysis for XM1 Tank System, ASARC III," prepared by the U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland 21005, and by U.S. Army Medical Research and Development Command, Fort Detrick, Frederick, Maryland 21701.

The driver's position for the buttoned-up, or closed hatch, using periscopes is presented in Figure 5, along with the open hatch position and the closed hatch position using the night vision device. The commander's station is presented in Figure 6 along with buttoned-up alternative positions. In general, the driver will have the capability of driving the vehicle onto the RPAR from the friendly bank and off of the RPAR onto the enemy bank. He does not, however, have the vision capabilities to control the RPAR, being extremely limited with forward vision only. The vehicle commander, under buttoned-up conditions, has, with the exception of hull obstacles, 360° visibility and is the crew member with the greatest capability of RPAR control. The buttoned-up vision attributes for a single periscope or a single vision block is presented in Table 3 for the fixed eye position as well as for eye and head movement. The normal position will be the fixed eye position for the driver, in particular, and for the commander under most instances.

The navigation/vision capabilities in general for the classes of armored vehicles, namely, tanks, reconnaissance, armored personnel carriers, self-propelled guns and missiles are presented in Table 4. In general, the commander has 360° capability for horizontal vision, 12° to 24° vertical for the tanks, and 7° to 60° for other vehicles. The driver is much more limited with horizontal and vertical straight ahead vision limited to $\pm$ 40° to 75° for the horizontal, and approximately the same as the commander for the vertical. See Table 2 for information on any individual vehicle type.

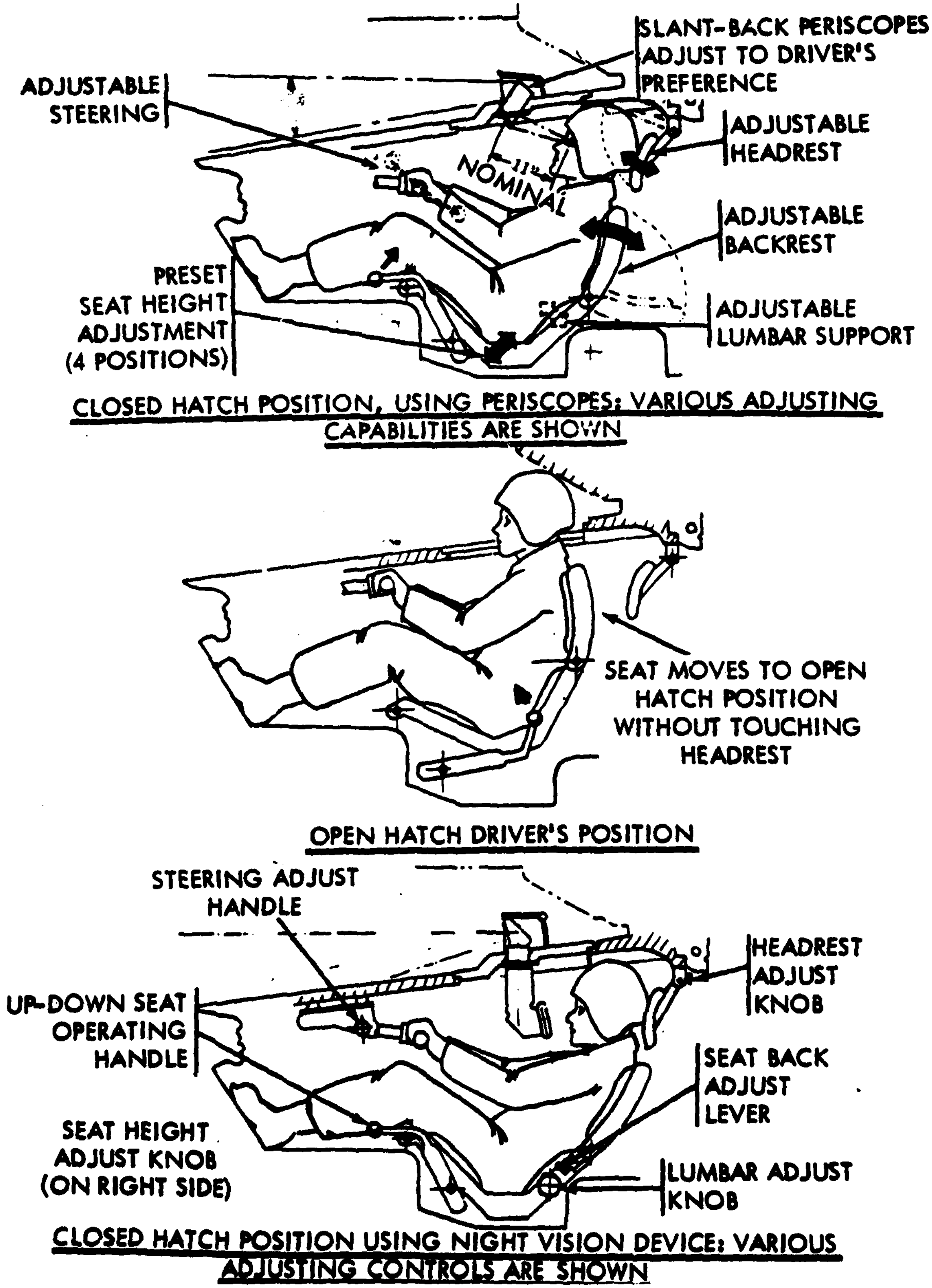


FIGURE 5. DRIVER'S POSITION - M1 TANK

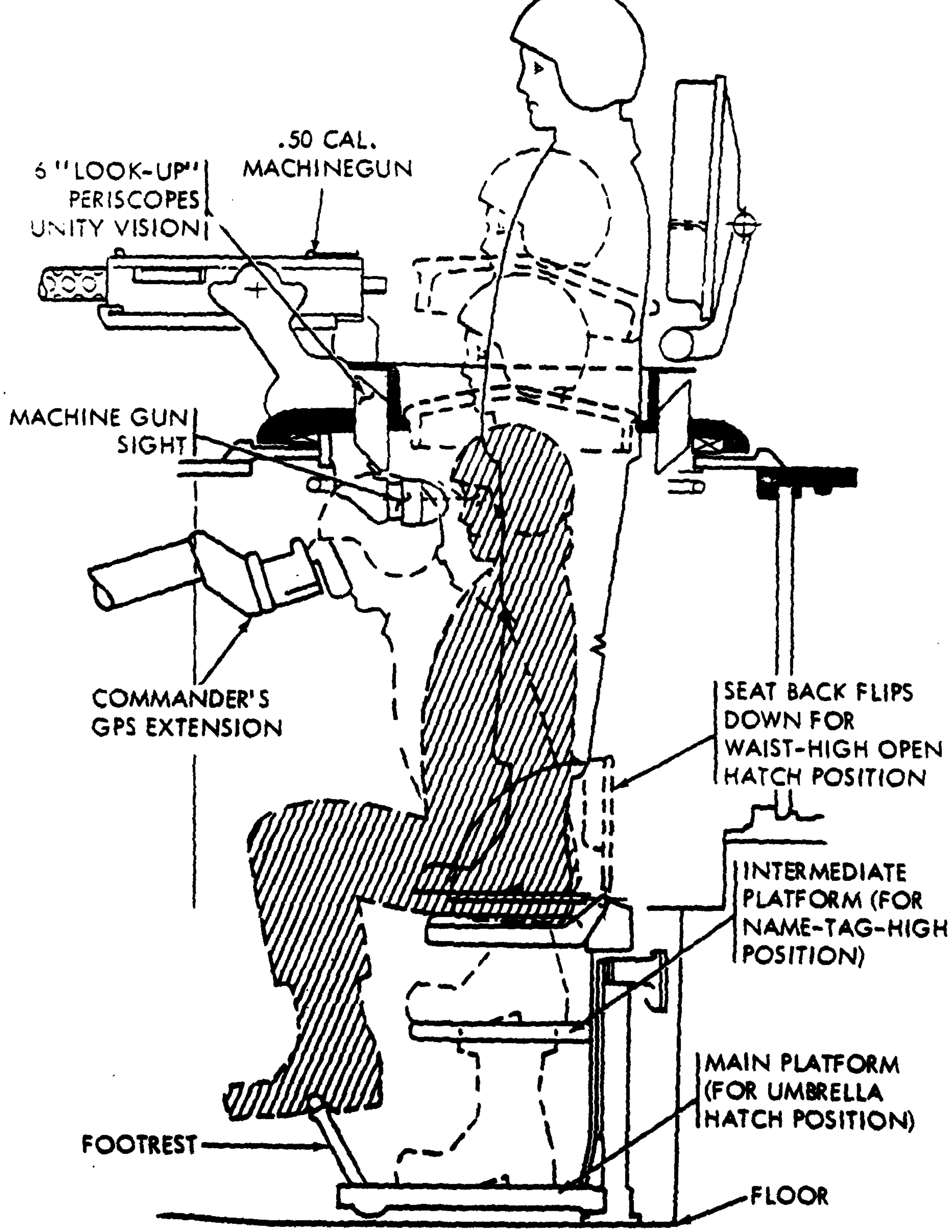


FIGURE 6. COMMANDER'S POSITION - M1 TANK

TABLE 3. BUTTONED-UP VISION ATTRIBUTES

		Periscope		Vision Block	
		Fixed Eye Position	With Movement	Fixed Eye Position	With Movement
Driver	Horizontal	27°	55°	30°	60°
	Vertical	11°	22°	8°	16°
Commander	Horizontal	27°	55°	40°	80°
	Vertical	11°	22°	12°	24°

Not above horizon without periscope.vision block adjustment

Source: HEL USATACOM.

TABLE 4. NAVIGATION VISION CAPABILITY

Vehicle		Commander	Driver
Tanks			
M485, M60A3 M551, M1 HIMAG, HSTV	H	360° EHOBS*	Straight ahead $\pm$ 25° to $\pm$ 85° DOT
	V	12° to 24° DOT**	8° to 22° DOT
Reconnaissance			
M3, M14 Commando Scout XM966	H	360° EHOBS	Straight ahead $\pm$ 40° to $\pm$ 75° DOT
	V	7° to 60° DOT	7° to 60° DOT
Armored Personnel Carriers			
M2, M113A1 AM331, V100, Commando Ranger LTVP-7	H	360° EHOBS	Straight ahead $\pm$ 20° to $\pm$ 75° DOT
	V	7° to 60° DOT	7 to 60° DOT
Self-Propelled Guns & Missiles			
M110, M107, M109 M108, DIVADS, M42, M163, M727, Chaparral	H	360° EHOBS	Straight ahead $\pm$ 15° to $\pm$ 75° DOT
	V	11° to 60° DOT	11° to 60° DOT

*EHOBS - Except Hull Obstruction Blind Spots.
**DOT - Depending on Type.

3.4 FINDINGS AND SUMMARY OF VEHICLE DATA

(a) The vehicles most likely to use the RPAR in the conduct of tactical missions are armored vehicles including tanks, reconnaissance vehicles, armored personnel carriers, and possibly self-propelled guns, howitzers, anti-aircraft guns, and surface-to-air missiles.

(b) The range in weight the raft will have to support is from slightly greater than 3 ST to as high as 70 ST.

(c) The mobility of the vehicles is from fording capability of one meter to fully amphibious. The climbing capability is approximately 60% for all vehicles, and the side slip capabilities range from 30 to 40%.

(d) Under buttoned-up conditions, the commander has the best vision capability of the crew and therefore would have the greatest control and communications capability. The driver's vision is limited to straight ahead $\pm$ 50° to 75° with limited vertical vision capability of 8° to 11° and not above the horizon.

(e) The track, or wheel, interface with the RPAR ranges in width from 1.6 m to 3.7 m, and the wheel base, or track length on ground, ranges from 2.3 m to 5.0 m.

4. COMPONENT AND SUBSYSTEM CONCEPTS

4.1 INTRODUCTION

System concepts, keyed to the type of navigational and control used, were discussed in Section 2. Regardless of the overall system approach selected, a number of subsystem concepts must be developed for the RPAR. These subsystem concepts are discussed in this section and serve as a technology base for future consideration and development of the RPAR concept.

4.2 RAFT CONCEPTS

The configuration of the raft must reflect (1) the characteristics of the vehicles to be transported as summarized in Section 3, (2) the raft propulsion system and (3) transportability requirements. A strong technology base already exists, of course, in terms of both the current military wet-support bridge units which can be used for rafts or ferries and recent development work on self-propelled bridge sections. This background is used in the following subsections to develop a preliminary RPAR raft configuration to serve as a baseline concept.

The resulting configuration should be regarded as one approach among various options to which the remote control technology can be applied.

4.2.1 General Hull Configuration

Hull configuration has many constraints which limit the design choices. Buoyancy and stability dictate a hull 56 ft long by 20 ft wide by 4 ft deep. This will have to be divided and folded. In order to have only one type of unit, suitable individually as an MLC 35 ferry and joined with another to make an MLC 70 ferry, the 56-ft length can be divided into halves. Since both types of ferry are to be double-ended, i.e., with ramps at both ends, the ramps must be housed completely within the length, and, moreover, both ends of each unit must have sufficient vertical surface to provide adequate bearing surface when the units are joined into a large ferry.

Cross-sectional envelopes are shown in Figure 7. The proposed Dry Assault Bridge trailer permits a 4 ft x 10 ft load over the wheels. The Assault Bridge itself is 41 ft long and transportable by C-141. The M1 tank is 12 ft wide, which is the maximum size load to be carried by the ferry. The Improved Wet Bridge is 11.5 ft wide. A 10-ft width permits even division of the ferry hull and this is C-141 transportable. A trailer similar to that for the Dry Assault Bridge would permit one 4-ft deep section to be carried in the aircraft; the top layer, also 4 ft deep, would have to be demounted and carried separately or on a separate trailer if lifted by C-141.

Since the propulsion units (diesel) must remain upright at all times, the cross-section must be folded into three parts, 5-ft wings and a 10 ft wide center section containing the propulsion units. Since the lengthwise hinges lie within the tread width of the M1 tank, they must be beneath the roadway surface. Several alternatives exist, one being the Soss-type hidden hinge and another being a linked hinge. The general layout and dimensions of the ferry unit are shown in Figure 8.

It is noted that the deck of the unit consists of a level mid-portion and two sloping ends. When the ramps are housed, a level surface over the entire length of the unit is available. Both surfaces of the ramps are used as roadway. The length of the unit has been increased to 36 ft (from 28 ft) to offset the lost buoyancy in the bow and the added weight of the ramps, as well as to provide a longer level mid-portion of the deck.

With a 10-ft wide center section and a 12-ft wide tread of M1, the ramp must extend into the wing sections. Therefore, 2-ft wide wing ramp sections are provided to give a 14-ft ramp when required. If not required, these can be kept in stowed position. If they can be used independently, they do not require longitudinal hinging to the center section ramp. Moreover, since the main deck structure at the hinge line is not a continuous straight line because of the slope at the ends, only the middle 16 ft of the hull can be hinged for folding of the section. In order to transfer shear stresses between the hull sections at the ends, and between the ramp and

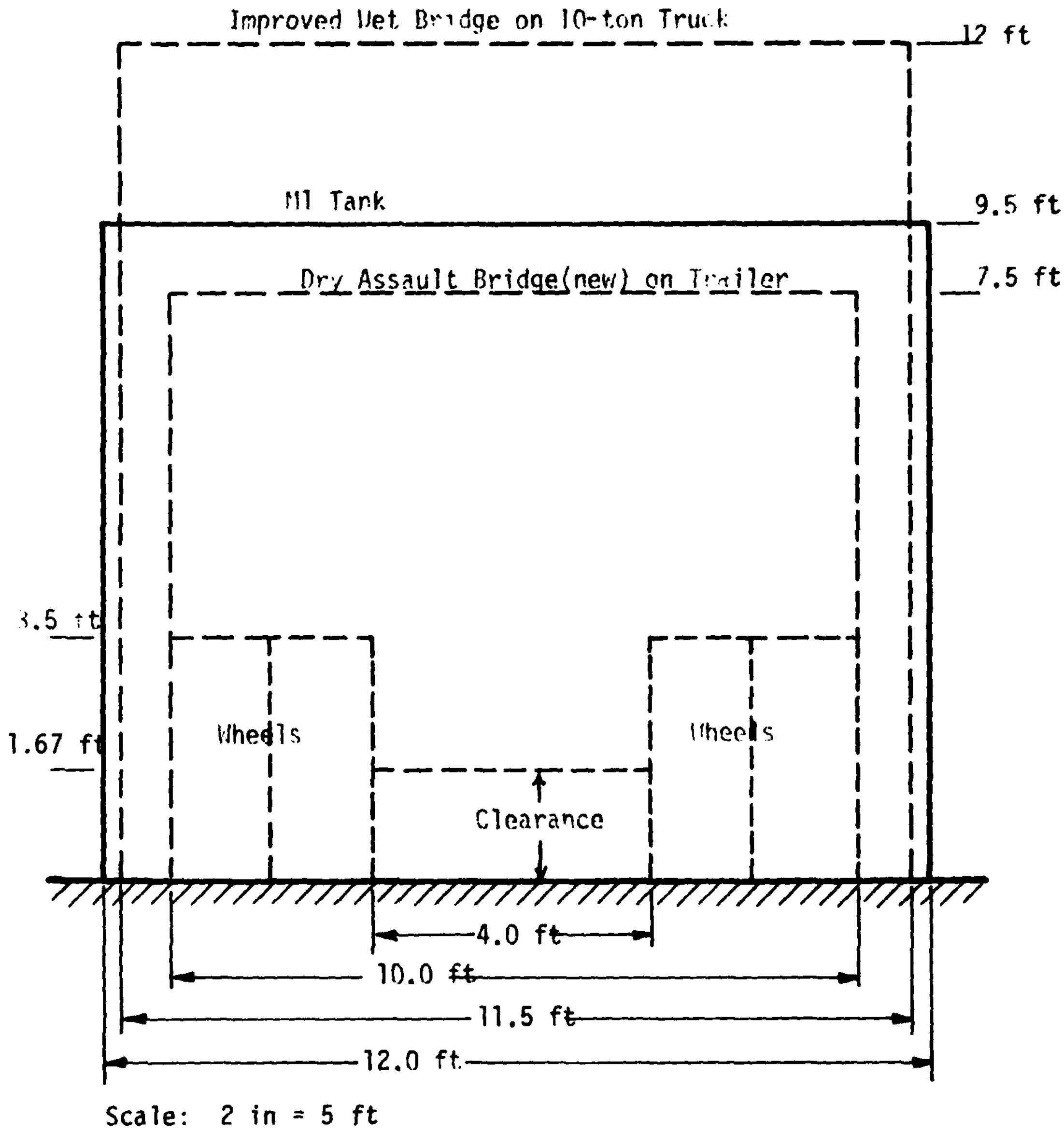


FIGURE 7. CROSS SECTIONS OF TRANSPORT ENVELOPES

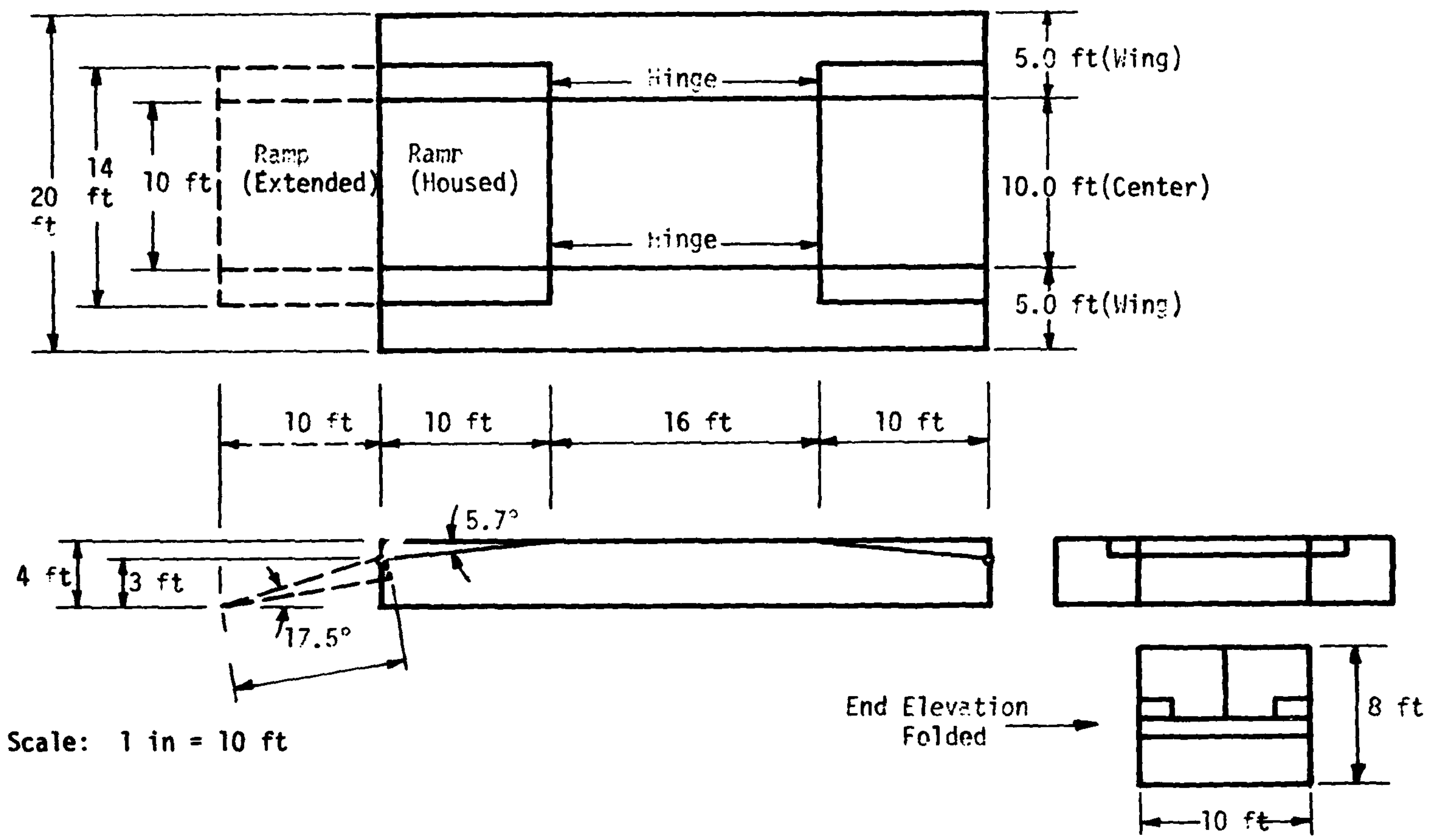


FIGURE 8. MLC 35 FERRY (HALF-SECTION)

ramp wings, locking pins can be inserted after unfolding.

Ramp geometry is indicated in Figure 9. It is necessary to minimize ramp length because of the deck length of the unit. A 10-ft ramp seems to give reasonable results and will meet the 1.5-meter above-water-level requirement when the ferry is loaded to the 3-ft waterline. However, the ramp will not engage a river bank that is 2 meters above the level. Ramp hinge requirements make shaping of the bow difficult. Furthermore, sufficient vertical mating surface with the adjacent raft unit must be retained. The result is the odd-looking configuration shown in Figures 9 and 10. This is inefficient and will require considerable power to achieve the 3.0 meters per second (m/s) required or the 3/5 m.s desired. The ramp hinge must be recessed in order for two sections to mate; however it is not "hidden" in regard to the ramp surface when extended. This thwartship hinge probably can be adequately protected or made heavy enough to permit vehicle passage without undue wear and distortion.

It will be impossible to fully stow the ramps when a vehicle is on board the ferry single unit, since the level surface is only 16 ft long. The ramps must be carried in raised position during transit. The main outboard portion of the ramp must be open grillwork in order to provide visibility from the various positions of the vehicles. It is possible that a small section of the ramp near the hinge can be made as a watertight pontoon, but the larger part of its length must be open structure. The large double-unit ferry will have 32 ft of level deck available and the ramps can probably be fully stowed. The overall length of the M1 with gun extended forward is 32 ft.

Design of the exact bow configuration and shape of the hinge-end of the ramp may indicate improved possibilities. However, the general limits indicated seem to hold.

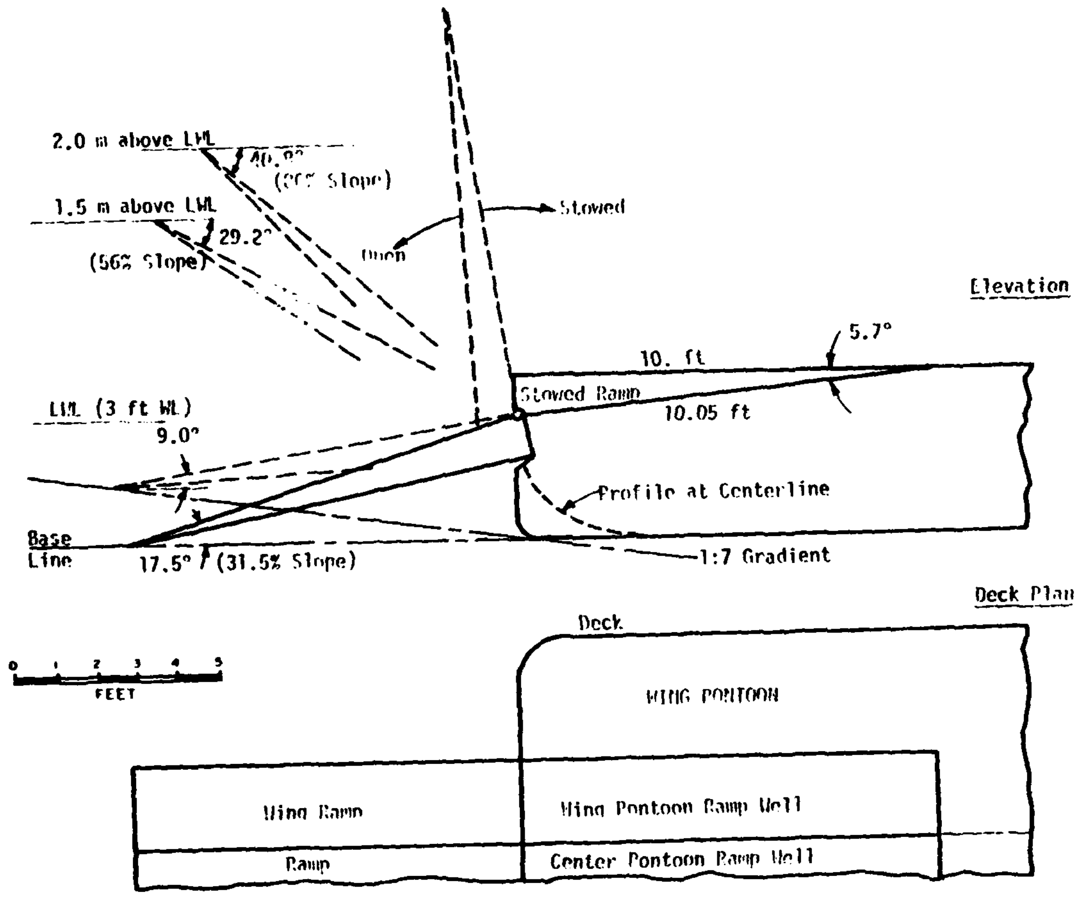
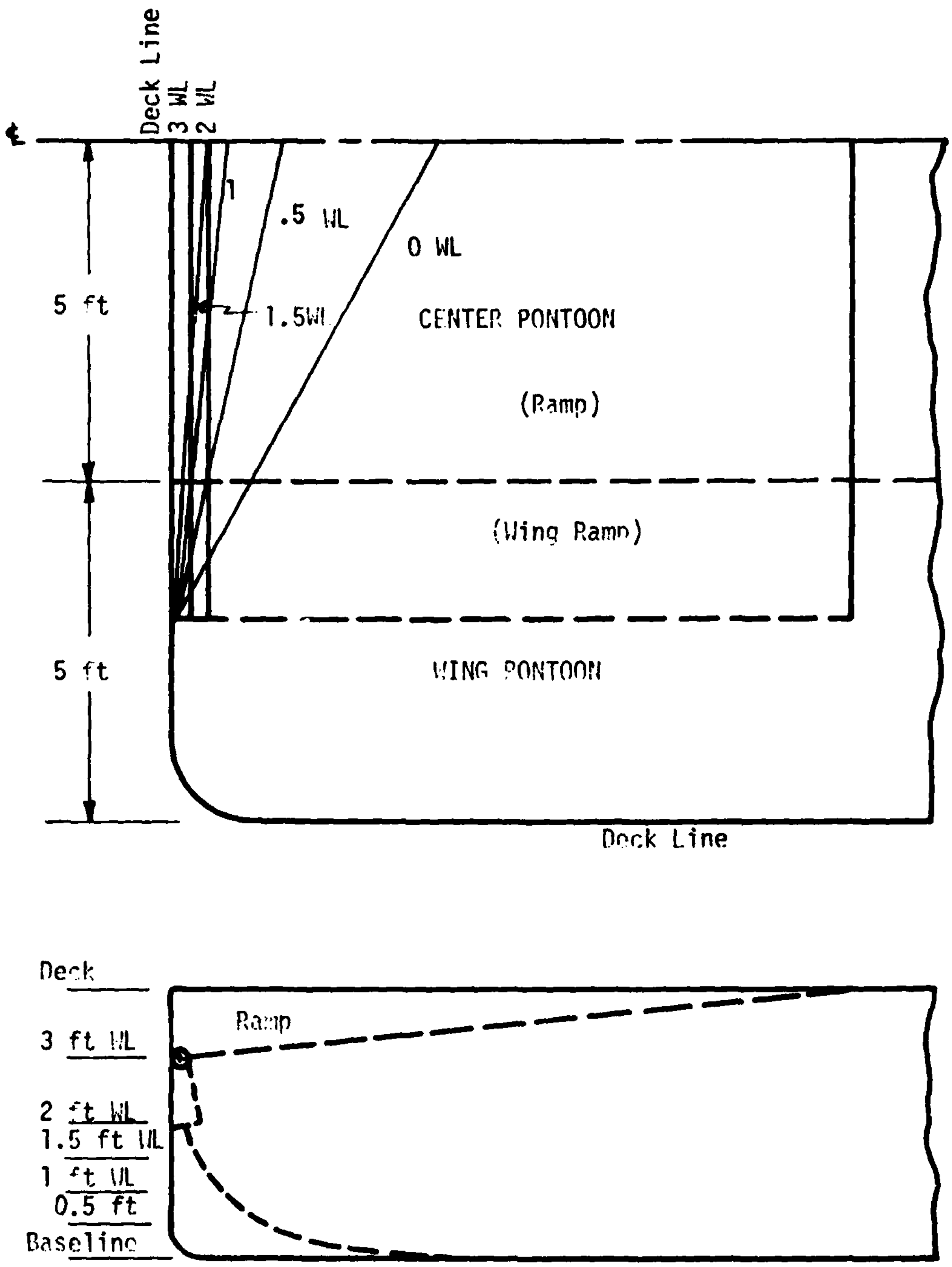


FIGURE 9. RAMP ARRANGEMENT



Scale: 2 in = 5 ft

FIGURE 10. HULL LINES AT ENDS (SYMMETRICAL)

Four propulsors are required, two in each unit. These two units must be accommodated within the 4 ft x 10 ft x 32 ft center pontoon. The propulsors themselves can be on the centerline or at diagonal corners of the center section. The two-unit large ferry will then have four power units, and the individual unit or small ferry will have two. Hydraulic or electric power take-offs from the diesels can provide stowage and extension power for the folding of the sections and for the ramps. This development is summarized in Table 5. It is noted that the resulting base case configuration is minimum size; a hull of larger platform would increase stability and survivability but would complicate the transportability and roadability of the unit.

4.2.2 Center Section

For the single module (the MLC 35 ferry) the configuration of the center section is examined both for load-carrying and for accommodation of two propulsion units. The single module has a level deck length of 16 ft as shown in Figure 8 with 10-ft ends at a slope of less than 6 degrees. The 16-ft length is sufficient for all tracked vehicles, although they must be centered carefully. In regard to wheeled vehicles, the 10-ton standard truck has a wheel base of about 5.9 m or 19.5 ft. If such a truck is placed on the ferry, the footprint of the wheels would be on the sloped ends, but only about 3 inches below the level of the level deck. This is considered acceptable.

The section probably will require internal supports at the breaks in the deckline at each end of the 16-ft level length. These transitions will bear a load concentration when a tracked vehicle passes over them. Therefore, it may be assumed that a clear engine space of only 16-ft length will be available. In order to test the feasibility of accommodating the propulsion plants in such a space, we have used approximate envelopes for diesels and propulsors of necessary size and considered possible arrangements. Figure 11 indicates two alternatives. These machinery layouts are given only to substantiate the feasibility of using a space of 16 ft x 10 ft by 4 ft high for the two units. For matters of damage control

TABLE 5. FERRY CONFIGURATION

Requirements:

Up to MLC 70 loads
Trailerable
Ramp elev: from WL 1.5 m min; 2.0 m desirable
Speed: laden 3.0 m/s min; 3.5 m/s desirable
light 3.5 m/s min; 5.0 m/s desirable
Unsinkable
Suitable for 1.7 bottom slope

Length, Beam, Draft and Proportions

Beam for stability laden: 20 ft: GM = 5.6 ft
16 ft: GM = 1.8 ft
Assume 1 ft light draft.
Then, overall: length 56 ft beam 20 ft
depth 4 ft draft 4 ft
L/B = 2.8 B/D = 6.7
1/2 length for MLC 35 load: 28 ft x 20 ft x 4 ft x 3 ft
Assume bottom-mounted pump-jet steerable propulsors.
Then, 2 propulsion units required per 1/2 ferry for steerability,
a ramp at each end of the 1/2 ferry required for individual use of 1/2 unit.

Hull Division

28-ft length of 1/2 ferry appropriate (the trailered new dry assault bridge is 41 ft long).
Additional requirement: air-cooled main diesels must remain upright at all times.
Then the section of the ferry containing the propulsors must remain upright.
Additional requirement: the stowed cross-section must meet roadability requirements.
We arrive at a 10-ft width, and the overall scheme becomes one of a 10-ft wide (by 4-ft high) center section plus two 5-ft wide wing sections, to give a stowed section 10 ft wide x 8 ft high. Propulsion is located in the center section.
Each 1/2 ferry requires a trailer.

TABLE 5. (CONT'D.) FERRY CONFIGURATION

Ramps

The mid-section joint when the two 1/2 units are joined into a large ferry is at a point of maximum bending moment and hull stress; therefore the ends of the sections must be flush and the ramps fully stowable.

A 10-ft long ramp seems acceptable. We recommend a 10-ft ramp the full width of the center section, with two wing ramps each 2 ft wide and not longitudinally hinged to the main ramp. Wing ramp use is optional depending on vehicle width (M1 width of track is 12 ft).

Results

The 1/2 ferry unit length is extended to 36 ft. This gives 10-ft sloped deck under the ramp; 16-ft level deck; and 10-ft at the other ramp. The extension takes care of losses in bouyancy due to shape, of weight increases, and of necessary length of level deck.

Heavy structural support will be required at the breaks in the deck. Therefore a clear engine space of 16-ft x 10 ft x 4 ft may be assumed. 2 propulsion units can be fitted into such a space. Other spaces will be foamed for solid buoyancy.

Hinging

The 10-ft width between hinge lines places the hinges under M1 treads (12-ft total track width). Therefore a hidden hinge of the SOSS type or other is required.

Because of slope of deck at ends, only the middle 16-ft of the hull joint line can be hinged.

The wing sections can be unfolded on the trailer for access and maintenance of the propulsion plant.

The wing sections will be unfolded before launch from the trailer. Ramps stay in stowed position until after launch.

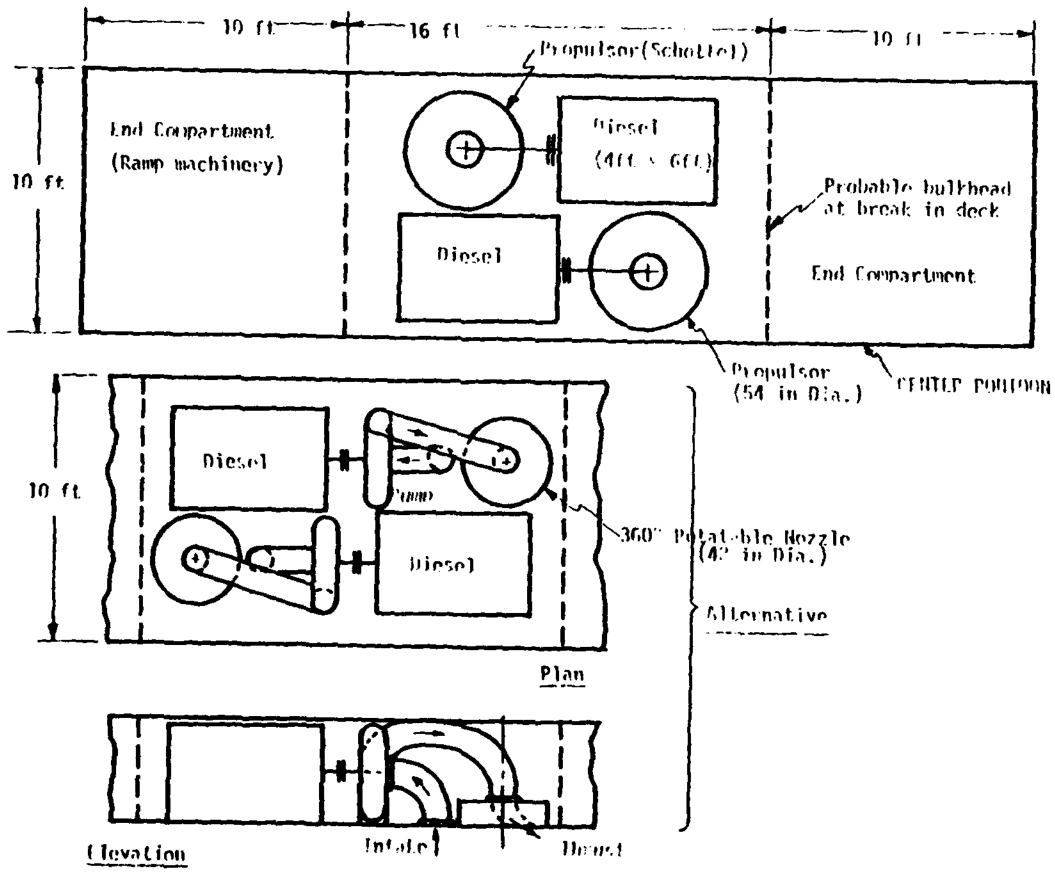


FIGURE 11. SCHEMATIC PROPULSION LAYOUTS

and survivability, it may turn out that a centerline subdivision, giving two separate compartments 5 ft wide, may be desirable. Likewise, a transverse bulkhead division of the two spaces is feasible, with the two shafts between diesels and pump-jets or pumps passing through glands in the bulkhead.

4.2.3 Wing Section Folding and Stowage

A variety of hinge concepts is feasible. These include the Soss-type hidden hinge; a rolling hinge with a rotating link, which likewise provides a protected "hidden" profile; a normal hinge with the pin at the hinge line, but protected by a grating which meshes in the closed condition and permits full 180° operation; or some form of bell crank. The characteristics of these hinge concepts are discussed in Appendix A. The criteria which may be applied to a selection between the various types are cost, complexity, ability to be powered, and vulnerability to damage or to debris on deck. Although these criteria have been examined briefly, we make no specific recommendation at this time.

Due to the configuration of the ferry which has been developed to this point, several characteristics become apparent. First, in all of the above types of hinge, their application here makes internal powering difficult and complex. Second, the ends of the ferry must remain clear and therefore external driving mechanisms would be impractical to be fitted as well as highly vulnerable to damage.

Simplicity and low cost remain as major considerations in development of the deployment/stowage mechanism. Examination of these processes, in conjunction with an assumption of a hinge line at the deck-level edges of the center section and the adjoining wing section leads to several conclusions.

(a) Requirements

The ferry will have to be unfolded while on its carrier, both during maintenance and exercise cycles, and during operations. The wing sections must be lifted as they rotate upward and outward until their equilibrium point is reached. This point is reached when the center of gravity of the wing section is directly above the hinge line. This point is expected to be reached in the range of 48° to 55° of angular travel of the wing section from its stowed position.

Beyond this equilibrium point, the wing section will tend to descend under the force of gravity. If this deployment were to take place in the water, the water itself would provide considerable damping effect and a gravity drop would be permissible. However in air, such a drop would place excessive loads in the hinge and impacts upon the sides of the sections. A braking device is required.

The reverse situation exist during stowage of the wing sections. They must be raised through an arc of somewhere in the range of 125° to 132° to the equilibrium point, and then lowered for the remainder of the 180° travel, to the fully housed position. Here also a braking or cushioning device is required.

(b) Constraints

Any devices or linkages must be below the deckline when the sections are deployed. The ends of the ferry must remain clear. The system must be operable when the pontoons are in stowed and stored condition, i.e., the cycle must be able to be initiated manually when the ferry is in stowed condition on its carrier. Retrieval and stowage without power on the ferry should be possible.

(c) Concepts

The depth of the hull (approx. 4 ft) and the 180° travel of the wing sections make it difficult to fit a lever arm inside the hull. The torque that would be applied to the hinge would be high. External linkages therefore are desirable, but these invariably fall afoul of the clear deck requirement in open or in closed condition. A large variety of linkages and drives were considered, and the following arrangement has been developed.

One part of the system is a straight-line hydraulic piston facing nearly the vertical and ending with a roller bearing against the deck -- in stowed position -- of the wing section. With a travel of 2 to 2.5 ft, such a ram would raise the wing section to its equilibrium point. Conversely, during folding, this hydraulic piston would permit slow lowering of the wing section by use of a controlled bypass line. When the ferry is stowed on its carrier, initial raising of a section could be accomplished by an external hydraulic fitting and connection to a manual hydraulic pump. Such a method might be employed when it is necessary to have access to a deck hatch for engine or propulsor inspection and maintenance. Once an engine has been started, a hydraulic pump power take-off would supply the pressure required for this piston and other hydraulic devices on board. The ram head would be recessed into the deck when not in use.

The second part of the system is a two-legged linkage which is powered only by a cable rig as shown in Figure 12. The apex of the two legs, both of whose bases are roughly at deck level, is joined to a similar point for the other side by cables leading through a double-sheave block on the centerline of the ferry. During deployment of the wings, the cable is braked to control the descent of the wings. During stowage, the married cables are taken on a winch to raise the wing sections past the equilibrium point, where the hydraulic ram assumes the load for the remainder of the lowering.

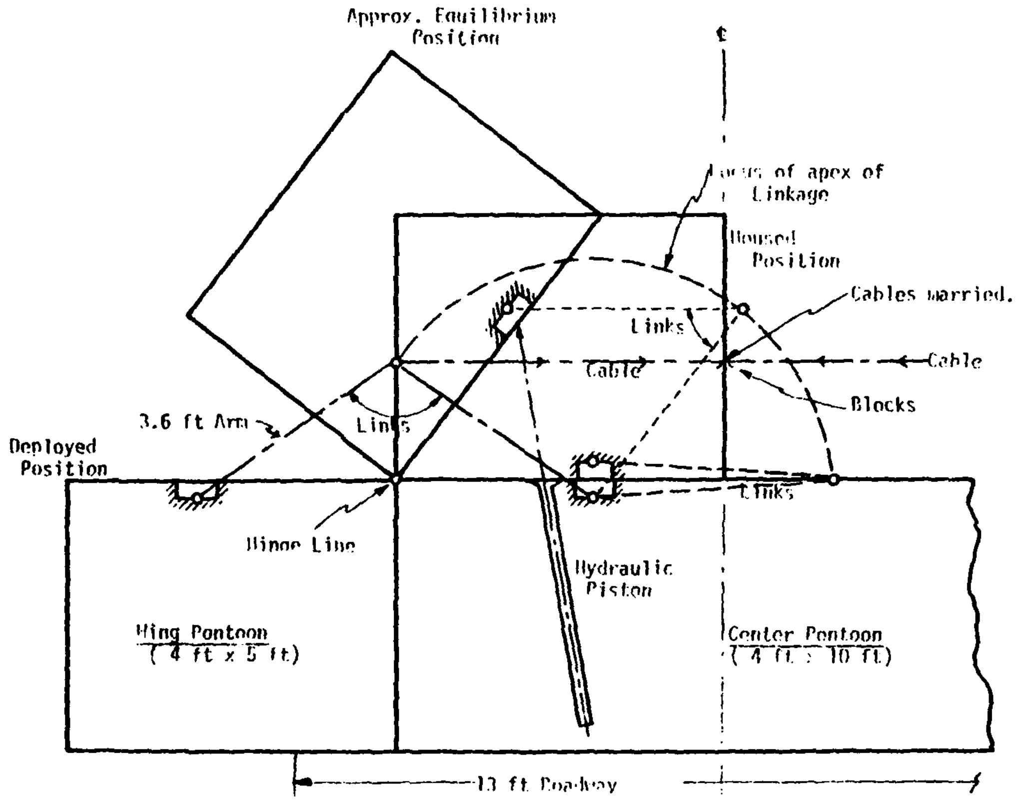


FIGURE 12. DEPLOYMENT AND STOWAGE SYSTEM

While it is desirable and feasible to recess the linkages into the roadway (deck) surfaces in the stowed condition, the linkage must be removed after extension of the wings, or at least one end must be portable. The wing section point can be placed outboard of the roadway and the linkage stowed longitudinally on this deck section.

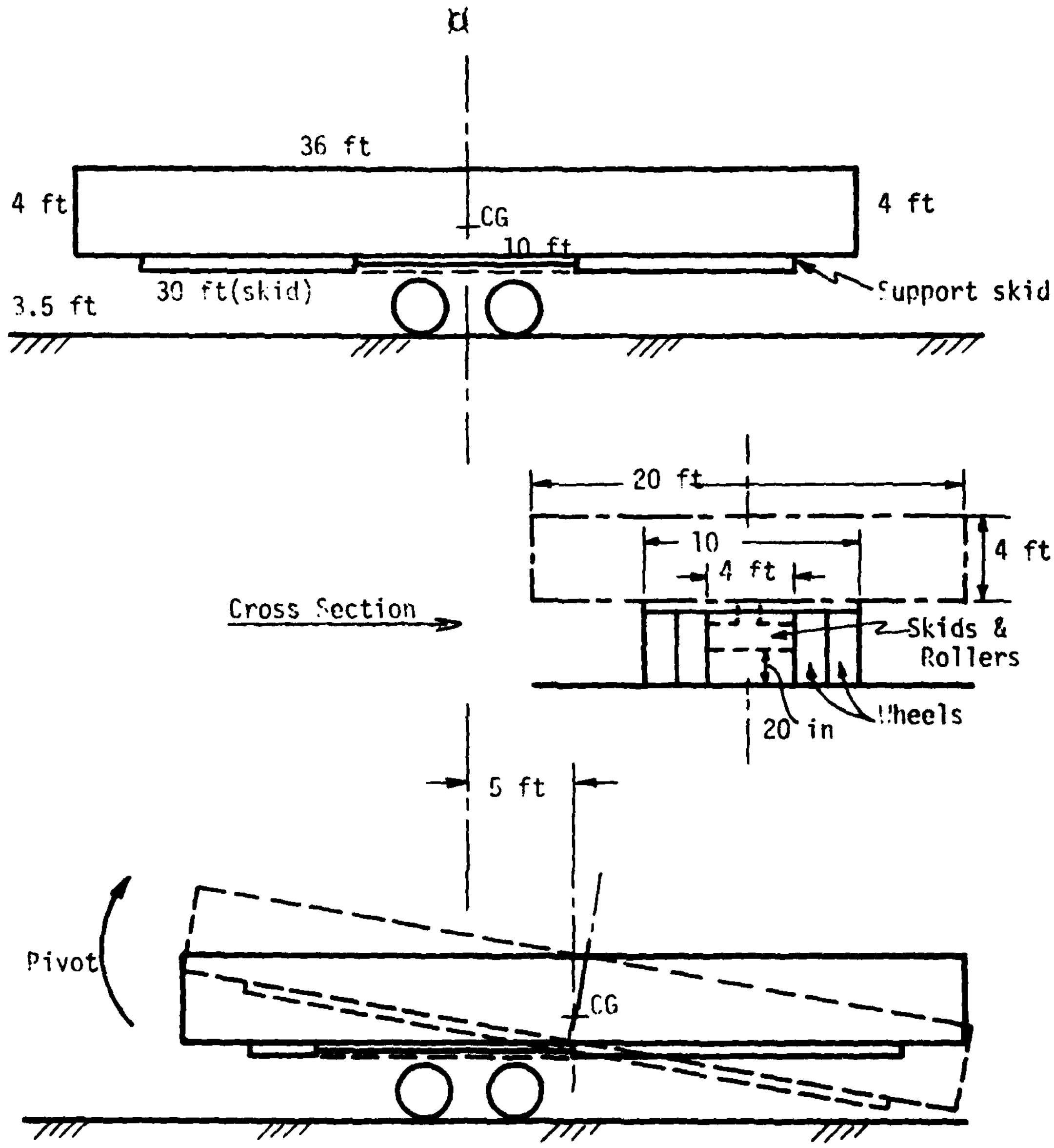
The advantages of this system seem to be simplicity and light weight. Deployment on the carrier requires limited hydraulic power for the ram plus a braking device for the cable. Retrieval of the ferry would be in deployed state; after the ferry is on the carrier, the same winch or power source used for hauling it onto the carrier can be used to fold the wing sections. During the final stage of stowage, no power is required on the hydraulic rams; they only absorb energy.

4.2.4 Raft Launch

The process of launching the unfolded raft from its trailer has been examined under static conditions. This covers the case of a slow and restrained launch and highlights any difficulties which might arise. If a high-speed dynamic launch is necessary or contemplated, the behavior of the hull would differ to some extent.

Launch statics are highly dependent on the configuration of the trailer. In this instance, we again have used a short trailer, under the center of gravity of the pontoon. It has a 10 ft x 10 ft bed and a height of 3.5 ft. The raft sits on skids which in turn slide on rollers in the trailer. The skids can pivot about a roller at the end of the trailer bed, as shown in Figure 13.

The details of this examination are given Appendix B. It suffices to give here the general conclusions of this examination.



Scale: 1/8 in = 1 ft

FIGURE 13. TRAILER CONFIGURATION AND LAUNCH

The assumed launch arrangement provides the capability of launching the raft in a range of shore slopes between about 10° and 45°, without immersing the trailer. Launch for embankments of about 2 meters height (6.6 ft) also is feasible. A slope of 10° is about 1:6 and does not quite meet the 1:7 requirement. However, with partial immersion of the trailer this lower limit of the range can be extended to the necessary 1:7 slope.

In shallow water, launch problems become more severe. However it must be recalled that the vehicles themselves have a fording capability; the M1 tank can be immersed to some 4.5 ft. In that event of a very low bottom gradient, the ferry unit may require launch at a different point on the shore that at the ultimate embarkation point.

It is noted that, in Appendix B, it is assumed throughout that the center of gravity of the hull is moved 5 ft past the end of the trailer bed (a=5). Any value of "a" greater than zero will cause the hull to tilt downward. Conversely, at values of "a" less than 5 ft, the pontoon will pivot back upward at values of angle and draft less than those derived in the numerical examples.

On the trailer itself, a rack and pinion arrangement or a hydraulic linear drive will be required to move and control the motion of the skids and the hull relative to the trailer bed. If the forefoot of the hull has reached the bottom when it tilts off the trailer, the hull can be floated off by moving the trailer up the shore, with the heel of the hull moving down the skids. This latter relative motion will require an adequate sliding mechanism at that point and may require that a force be applied; the latter can be provided by a cable rig powered at the trailer or the tractor vehicle. Guide channels in the hull bottom may be required to mate with the skids.

Retrieval of a raft would reverse the process. The trailer and the deployed skids would be placed at the shore and a cable and winch arrangement would haul the hull onto the skids. The same cable arrangement could be used to house the skid plus hull on the trailer; alternatively, the hydraulic or rack and pinion arrangement could be used for this second movement. During both these processes, the weight of the hull, is being raised and commensurate power must be provided. In the steep shore case, the center of gravity of the hull moves upward at an angle of about 54° and the retrieval force for a 12 ST raft becomes 9.7 ST.

The examination performed in the examples of Appendix B is aimed at demonstrating the feasibility of launching and retrieving a raft of the assumed dimension from a short trailer. The examples indicate that the general requirements can be met. However, further work remains to be done when the parameters of the ferry unit become firm, and when further study is performed upon the design of the trailer; the assumptions used in Appendix B are stated in that discussion.

4.2.5 Survivability

The loaded MLC 35 ferry unit at a draft of 3 ft has 1-ft freeboard and a reserve buoyancy of about 17.5 ST. This value takes into account the loss of buoyancy due to the ramp wells at drafts over 3 ft.

The space designated for propulsion is 10 ft x 16 ft x 4 ft or 640 cu ft. At a permeability of 0.85, flooding of this space would add 17 ST to total weight of the unit. The ferry would float with the deck awash.

If the propulsion space is subdivided in half longitudinally by a watertight bulkhead between the two propulsion installations, each half, if flooded, would contribute 8.5 ST to total weight. With one half flooded, some 7 in. of freeboard would remain, provided the craft remained of an even keel. However because of the unsymmetrical buoyancy, a severe list would develop.

A similar situation occurs if the propulsion space is subdivided athwartships by a watertight bulkhead between diesel engines and propulsors. However, flooding of one space would cause less trim than the list in the other example since the length of the unit is 1.8 times its beam. Moreover it would be much easier to move the ferry's load fore-and-aft in compensation than it would be to move it sideways.

Since flooding of the entire propulsion space results in a marginal condition, subdivision is recommended. In view of the marginal stability and the difficulty of compensation, longitudinal subdivision alone is not recommended. Athwartships subdivision alone, or subdivision at the midlength of both dimensions, is recommended.

The ends of the center section and the wing sections can be foamed. Small voids will be required for ramp operating mechanisms. At a weight of 2 lbs/cu ft for fire-retardant foam, these 1235 cu ft will add about 1.2 ST to the weight of the ferry unit.

4.3 PROPULSION SYSTEM

4.3.1 Introduction

This section discusses the propulsion system required to power RPAR raft units of the type developed in the preceding section. The thruster requirements and limitations are similar to those which have been studied in earlier investigations for powered bridge units.* The applicable technology is the same, especially the 360° rotatable thruster mounted in the hull bottom.

*Arthur D. Little, Inc., "Definition of an Improved Wet Support Bridge Concept and Related System Analysis," October 1981.

4.3.2 Propulsion System Requirements

(a) Thrust

Without extensive experimental studies, it is difficult to predict accurately the amount of thrust required to power and maneuver a blunt, inefficient hull of the type which will be used for the RPAR. However, it is expected that the total thrust levels required at the 3.0- to 3.5-m/s raft velocities desired will be about twice the 1800-lb requirement for proposed powered bridge modules. Thus, a baseline thrust level will be 3600 lbs for one RPAR module or 1800 lbs/thruster at 3.5 m/s, assuming two thrusters per module.

(b) Direction of Thrust

In the normal operations of RPAR modules, thrust may be needed in virtually any direction relative to the module itself. Thus, the thruster must be steerable. Maneuverability and response are greatest if the thruster can be steered or pointed at any angle throughout a complete 360° rotation relative to coordinates fixed to the module. However, this capability may not be required if a turning moment can be applied; the module can be rotated by use of the thrust moment until an available thrust direction is reached. Thus, the range of steerability was reserved for possible trade-off against other desirable features.

(c) Thrust Moment

No specification has been set for the required thrust moment or, for that matter, the rate of turn of the module.

One method for setting a tentative moment specification consistent with the above thrust requirements is to assume that the RPAR module is crosswise to the stream and that half of its length is in calm water or eddies associated with the shore effect while the other half is in fast water that imposes a drag consistent with the required total thrust (i.e., 1800 lbs on half of the hull). In this case, the reaction moment to keep the module from rotating would have to be 16,300 ft-lb, assuming a module having the dimensions given in Figure 8. This would require a minimum thrust nozzle spacing of 9 ft, which is consistent with the dimensions of Figure 11.

(d) Thruster Configuration

In order to accommodate the folding wing hull described in Section 4.2 and to allow location in the center of each RPAR module, the thruster must be of the type which produces a thrust through the bottom of the hull. In order to allow operation in shallow water, the thruster cannot extend below the hull bottom to any significant degree. This limits the type of thruster used to the Schottel Pump-Jet or similar configuration.

(e) Propulsion System Height

The tentative RPAR hull dimensions limit the height of each part of the propulsion system to 4 ft.

(f) Logistics

The primary logistical requirement on the propulsion system is that it should be capable of running on the fuel used by the field army of the future. This is, of course, diesel fuel. Thus, the prime mover must be either a diesel engine or a gas turbine. Gasoline engines were not considered as candidates for the system.

(g) Maintainability

It is desirable that the propulsion system be located and mounted in such a fashion as to permit maintenance on the engine and/or thruster while the RPAR module is out of the water in storage. This dictates that the propulsion units must be mounted in the center section of the module as shown in Figure 11 and that the module must allow the unfolding of the wing sections while it is on the carrier or trailer.

4.3.3 Prime Movers

As noted earlier, the gasoline engine was eliminated as the primary power source for logistical reasons. Since a gas turbine does not appear to offer any significant advantages and carries a cost and complexity burden, the diesel engine is the logical prime mover.

With regard to diesel engines, a selection of power ratings, weights, and sizes in shown in Table 6. The basic trade-off is between the air-cooled and water-cooled types. When the weight of the cooling system is considered, the various water-cooled varieties are somewhat heavier than air-cooled engines with comparable power capacity. They are also somewhat longer, especially when the space required for the radiator or heat exchanger is included.

The critical dimensions for installation in the RPAR modules is the height of the engine which must be less than four feet. This dimension varies between about 36 inches and 46 inches for the engines shown with the smallest heights found in the Deutz units.

Other factors equal, an air-cooled engine is preferable to a water-cooled one for this application in view of its reduced weight, size, complexity, and maintenance burden. Of the air-cooled units, the Deutz is preferred due to its low profile.

The Deutz line of air-cooled diesel engines is a promising prime power source for the RPAR modules. The overall dimensions of three of these units were given in Table 6. More detailed specifications are given in Table 7 for the sizes of interest. Engine dimensions are shown in Figure 14.

TABLE 6. DIESEL ENGINE CHARACTERISTICS

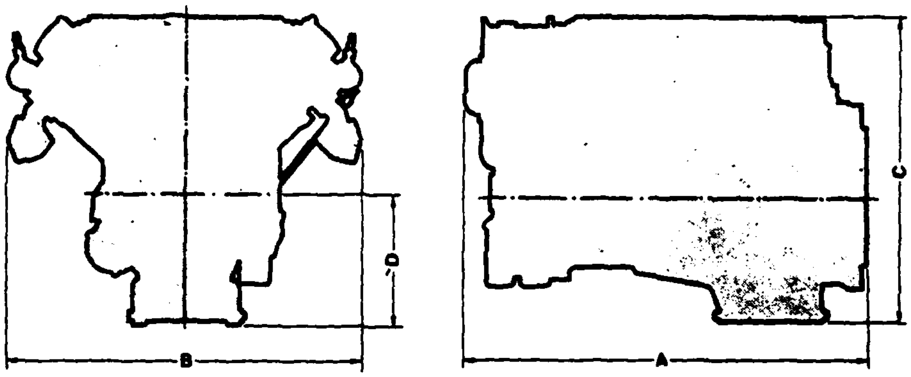
	DIN Horsepower			
	Continuous	Intermittent	Weight (lbs)	Length x Width x Height (Inches)
Air-Cooled				
Deutz BF6L913	135 @ 2,300	160 @ 2,800	1,069	44.3 x 27.9 x 36.3
Deutz F6L413	136 @ 2,300	163 @ 2,650	1,311	39.6 x 40.3 x 35.5
Deutz F8L413	182 @ 2,300	217 @ 2,650	1,668	49.1 x 40.3 x 35.5
Lister JAS6	155 @ 1,800	173 @ 1,800	2,150	67.4 x 31.1 x 43.3
Water Cooled				
Detroit 4-53T (without radiator)	175 @ 2,500	-	1,260	39 x 30 x 39
Detroit 6V-53T (without radiator)	233 @ 2,500	-	1,695	39 x 37 x 41
Isuzu E120 (6 cyl. in-line) (without radiator)	180 @ 2,220	214 @ 2,200	2,205	57.5 x 29.4 x 46
Isuzu 8MA1 (8 cyl. V-block)	256 @ 2,400	285 @ 2,400	2,778	55.2 x 40 x 46.4
Caterpillar 3208T Marine V-8 (without heat exchanger)	200 @ 2,400	260 @ 2,800	1,880	43 x 37 x 39
Caterpillar 3306 (6 cyl. in-line)	235 @ 2,000	290 @ 2,200	2,265	57 x 36 x 42

TABLE 7. DEUTZ DIESEL SPECIFICATIONS

Model		F 6 L 413							F 8 L 413						
No. of cylinders		6 V							8 V						
SAE adapter housing	Size	1 + 2							1 - 2						
Bore/Stroke	mm	120 / 125							120 / 125						
Capacity	litres	8.48							11.31						
Compression ratio		18.0							18.0						
Rotational speed	rpm	1500	1800	2000	2150	2300	2500	2650	1500	1800	2000	2150	2300	2500	2650
Mean piston speed	m/s	6.25	7.5	8.33	8.95	9.65	10.4	11.05	6.25	7.5	8.33	8.95	9.65	10.4	11.05
Continuous rating ("A" to DIN 6270)	kW	59	83	90	95	100	–	–	92	111	119	126	134	–	–
(10 % overload capacity)	HP	93	113	122	129	136	–	–	125	151	162	172	182	–	–
BMEP at idem	bar	6.51	6.53	6.37	6.25	6.15	–	–	6.51	6.54	6.31	6.22	6.18	–	–
Intermittent rating ("B" to DIN 6270) (no overload)															
(a) heavy duty	kW	72	86	94	99	105	110	–	97	115	125	132	140	147	–
	HP	98	117	128	135	143	150	–	132	156	170	180	190	200	–
(b) light duty	kW	76	91	98	105	110	115	120	101	122	131	140	147	154	160
	HP	103	124	134	142	150	157	163	138	166	178	190	200	209	217
BMEP at idem	bar	7.17	7.15	6.93	6.91	6.77	6.51	6.41	7.14	7.19	6.95	6.91	6.78	6.54	6.41
Automotive rating (DIN 70020)	kW	–	–	–	–	115	121	125	–	–	–	–	153	163	169
	HP	–	–	–	–	156	164	170	–	–	–	–	210	222	230
BMEP at idem	bar	–	–	–	–	7.08	6.85	6.68	–	–	–	–	7.06	6.88	5.77
Max. torque (automotive rating)	Nm	504							672						
at speed	rpm	1600							1600						
Min. sustained working speed	rpm	1500							1500						
Min. idling speed	rpm	600							600						
Specific fuel consumption	g/kWh	217							217						
	g/HPh	160							160						
	lbs/HPh	3527							3527						
Max. lube oil consumption as referred to fuel consumption	%	1 %							1 %						
Starting method		EL							EL						
Max. continuous inclination of standard sump:															
fan end	deg.	30							15						
flywheel end	deg.	30							15						
LH or RH side	deg.	30							15						
Shipping volume (seaworthy packing)	m³	1.3							1.5						

EL = electric starter

V-type engine



	A mm	A in	B mm	B in	C mm	C in	D mm	D in	G* kg	G* lb
F 6 L 413	1006	39 5/8	1022	40 1/4	898	35 3/8	388	15 1/4	595	1311
F 8 L 413	1247	49 1/8	1022	40 1/4	901	35 1/2	381	15	757	1668
F 10 L 413	1412	55 5/8	1022	40 1/4	942	37 1/8	360	14 3/16	925	2039
F 12 L 413	1576	62 1/16	1022	40 1/4	942	37 1/8	360	14 3/16	1090	2403

* Net weight to VDMA. Seaworthy packing: 25 % of net weight.

FIGURE 14. DIMENSIONS OF DEUTZ DIESEL ENGINES

4.3.4 Thrusters

As noted earlier, the requirement that the RPAR module operate in shallow water and the limitations imposed by the joining of individual modules makes it necessary for the thrust or propulsion unit to be either flush with the bottom of the module or installed at the bow and stern below the waterline.

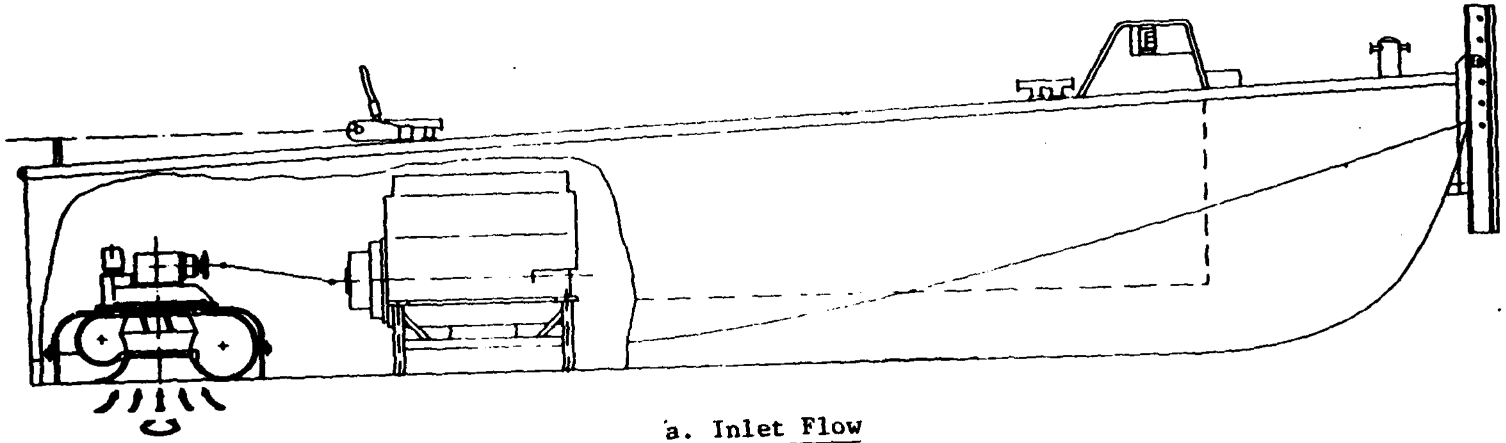
Since the Schottel Pump-Jet is the only thruster found that can be mounted flush with the bottom of the module, it was designated as the baseline thruster for the proposed system.

The Schottel Pump-Jet is basically a special mixed-flow pump designed to mount flush with the bottom of a boat, as shown in Figure 15. A cutaway drawing of the Pump-Jet is shown in Figure 16. Water enters axially (vertically upward), its energy is increased, and it is discharged tangentially with a downward component. The tangential discharge direction can be rotated 360° about the vertical axis by rotating the inner pump casing, giving complete directional control.

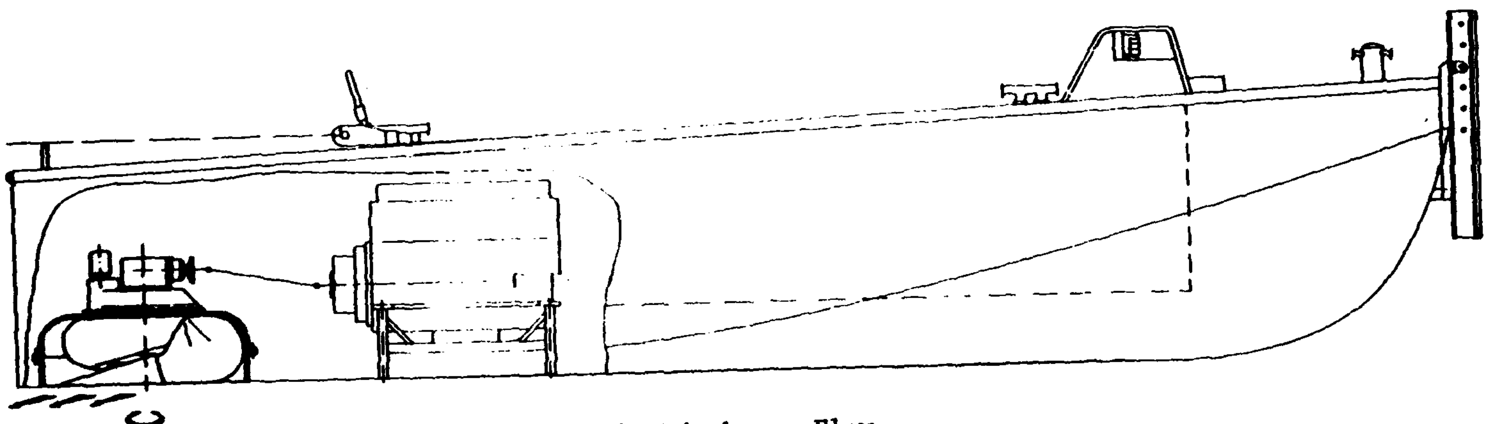
The standard unit is the SPJ-50, which requires a 1200-m (47.2-in.) diameter opening in the hull bottom. The major specifications for this unit are given in Figure 17. The maximum thrust of 10,000 Newtons (2248 lbs) is consistent with that required for each thruster in a RPAR module. As shown in Figure 17, the input torgue required at 2300 rpm is 500 Newton-meters (368 ft-lbs) to achieve this thrust level. Thus, the total required shaft power is about 160 hp at 2300 rpm.

4.3.5 Thruster-Engine Matching

The Schottel SPJ-50 requires about 160 shaft horsepower to deliver 2248 lbs of thrust at 2300 rpm. Referring to Table 7, it can be seen that the appropriate Deutz engine is the 8-cylinder V-block engine, Model F8L413. Thus, this engine is recommended as the baseline power plant.



a. Inlet Flow



b. Discharge Flow

FIGURE 15. SCHOTTEL PUMP-JET MOUNTED IN A BOAT

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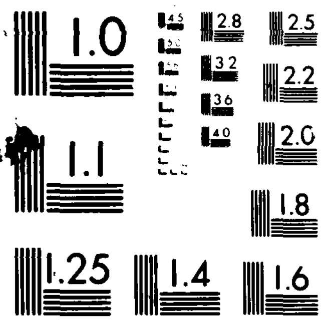

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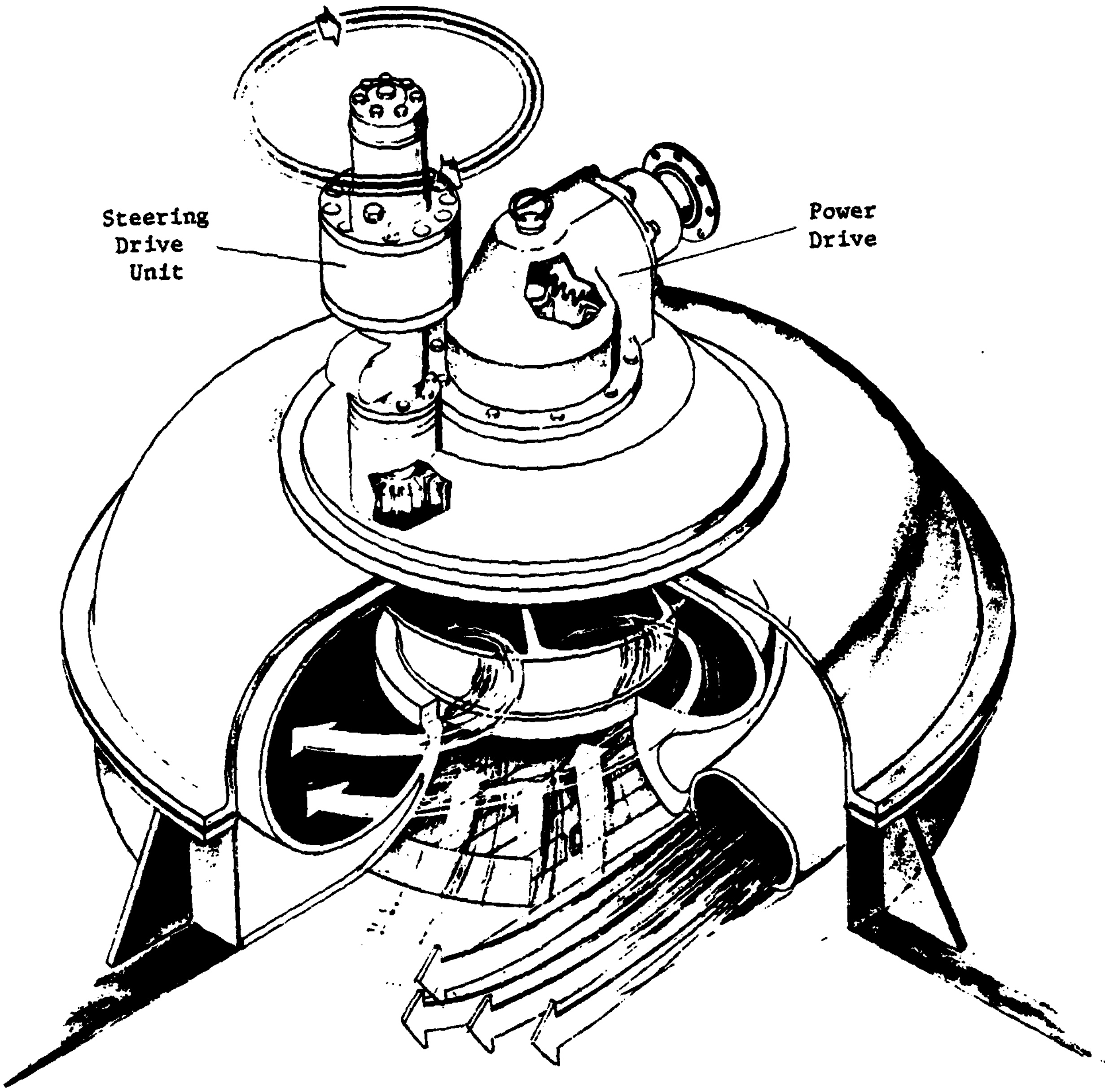
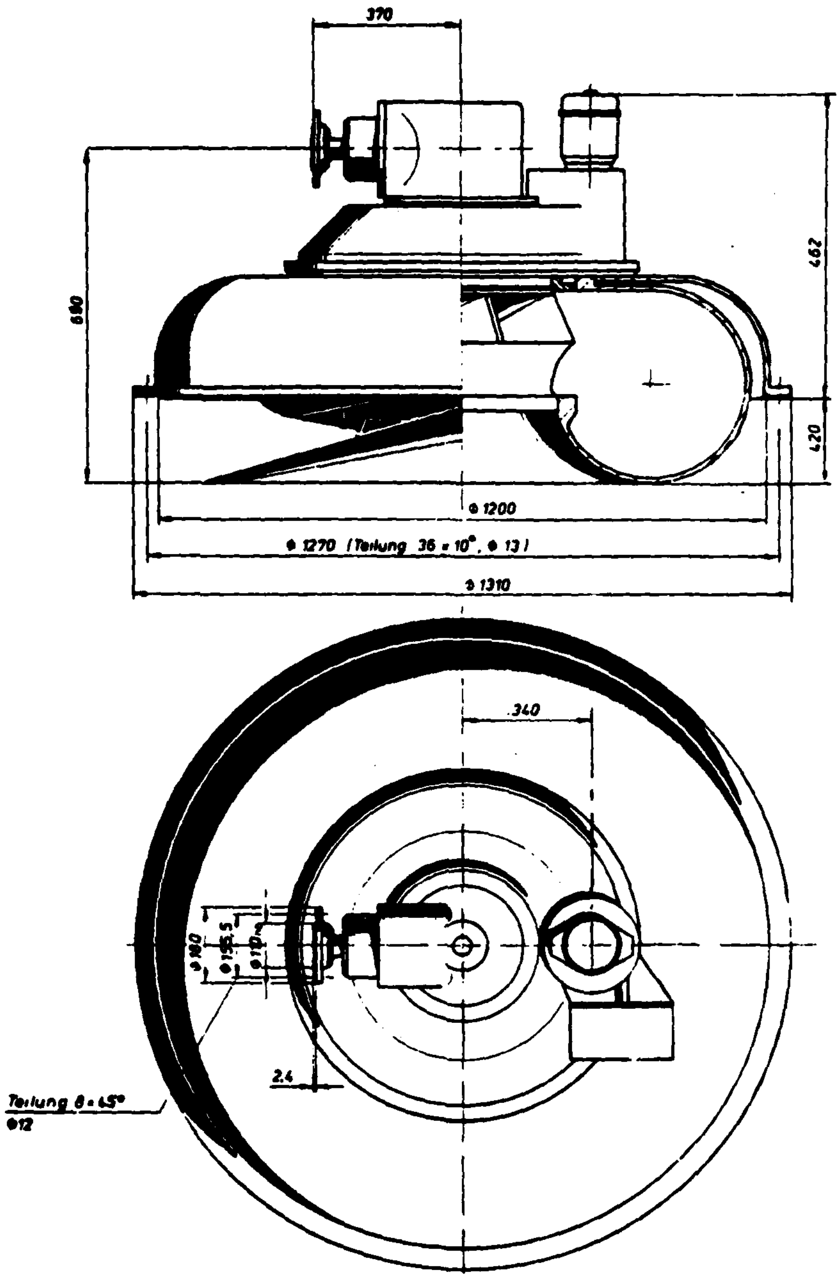


FIGURE 16. CUTAWAY VIEW OF SCHOTTEL PUMP-JET



(All dimensions in millimeters)

Input Torque (Nm)	500
Input Speed (rpm)	2300
Loss of Displacement (kg)	~200
Thrust (N)	~10,000
Weight (kg)	~250

FIGURE 17. SCHOTTEL SPJ-50 SPECIFICATIONS

4.4 ON-BOARD CONTROL SYSTEM

4.4.1 Introduction

In Section 2 of this report, several alternative methods of controlling or piloting the RPAR were discussed. Under manual piloting, several pilot locations are possible including:

(a) In the vehicle being transported
(b) On the near shore
(c) In an aircraft
(d) On the raft itself (probably only used as an emergency backup location)

For all of these potential modes of piloting, it is clear that there must be an on-board data processing system to handle the flow of data from the raft systems to the pilot and from the pilot to the raft systems. Alternatively, when the raft is operated in a fully automatic mode, the on-board control system must perform the logic functions necessary to operate on sensor data and perform the necessary corrective control action.

This functional description of the on-board control system can be achieved by a special-purpose computer along with appropriate interface circuitry to communicate with the raft systems and the data links to remote pilots.

This section discusses the general requirements of the on-board control system. Unlike many of the raft subsystems, this will be a special-purpose system, designed and developed for this specific application. It is anticipated, however, that the controller will make use of standard off-the-shelf electronic logic components and will not present any obstacles to feasibility or require any development beyond current state-of-the-art.

4.4.2 System Relationships

Figure 18 shows a block diagram of the entire system with the important system interactions and interfaces.

This system allows a remote pilot (or on on-board emergency pilot) to communicate through a radio link to the central controller and to receive data concerning the operating condition of on-board systems through the same radio link. The on-board systems controlled by the central controller are:

(a) Engines; starting, throttle
(b) Thrusters; direction of thrust
(c) Ramps; raise & lower

The condition signals that will likely have to be processed by the controller are:

(a) Engines; electrical, temperature, oil pressure, RPM
(b) Thrusters; direction of thrust
(c) Ramps; position
(d) Directional Gyro; heading

4.4.3 Central Controller

Most of the functions performed by the controller are, of course, straightforward data handling tasks. These include conditioning data received from sensors to input to the computer or the radio transmitter. Likewise, data received from the radio link must be conditioned for the computer.

Except for the ramps, which can be controlled with a simple binary signal, however, the on-board drives require a pre-programmed sequence of steps or an algorithm for their control. The most significant of these are as follows:

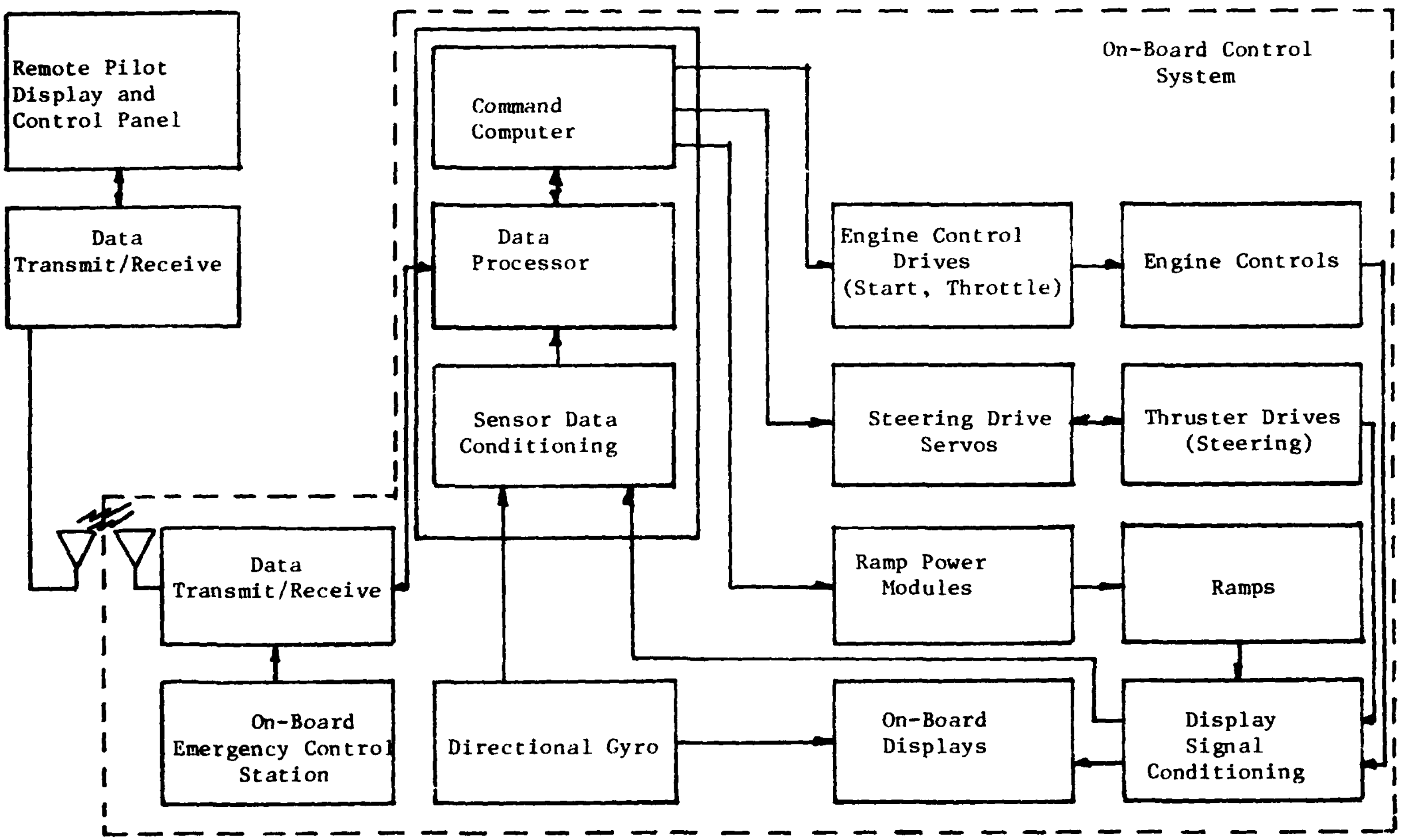


FIGURE 18. BLOCK DIAGRAM SHOWING SYSTEM RELATIONSHIPS

in consequence, its dynamic behavior. The ferry during such an interval is at the most remote point of the cycle. Its orientation is an essential factor in remaining safely beached in this unattended mode of control.

Although permanently installed mechanical devices such as anchors with winches, or spuds, would be effective, they also are large, heavy and would interfere with other primary function of the ferry, including interfaces with the control system. A dynamic solution using the installed control system appears to be a more satisfactory solution.

The position and orientation of the ferry at the shore must be maintained relative to the shore. In a river current, when the bow of the ferry is kept pressed against the shore, the ferry will tend to swing downstream about this point of grounding. The position of the bow can be maintained by providing a constant force normal to the shore line. Maintenance of orientation requires continuous measurement of the heading of the craft and the use of this measurement as feedback into the control system in order that the turning moment can be counteracted. The control system must sum the required normal force and the moment and derive appropriate settings for the thrusters.

Either two accelerometers in the horizontal plane or a gyroscope can be used as sensors. The accelerometers would be more difficult inasmuch as the angular rates to be measured are small. The gyro can be fitted to provide direct electrical information on heading and is simpler to apply. Such directional gyros are common in aircraft and weapons systems and do not represent procurement difficulties. The gyroscopic sensors therefore are preferrable.

(a) Engine Starting Sequence - The starting of each engine will, in general, require a sequence of operations. This sequence may include:

- clutch disengagement
- fuel priming
- glow-plug energizing
- starting motor
- throttle setting
- choke setting

(b) Thruster Directional Control - Each thruster direction will be controlled by a hydraulic or electric drive. The computer must translate a single joystick signal to the appropriate set of individual thruster servo commands. Two control modes are envisioned:

(1) Linear Thrust in which both thrusters (or four if two raft modules are used) must be controlled to produce thrust in the same direction.

(2) Turning Moment in which the thrust directions of each thruster (or pairs in the case of two raft modules) are adjusted to provide a turning moment or couple. In general, the maximum efficiency for turning moment can be achieved by making the thrust directions of each thruster (or pair) 180° from the other and 90° from the axis connecting their centerlines.

4.4.4 Auto-Pilot Position Holding

During the operational cycle of the ferry, a period exists when the vehicle is in the process of disembarking, or has just disembarked, when the ferry must remain in beached position without anyone on board. The conditions placed upon the ferry control system vary abruptly during this interval, particularly due to the changes in loading of the craft and,

Figure 19 provides a model of the beached ferry and its governing equations. The notation is defined as follows:

F_c = Lateral force exerted by the current.

F_b = Force required to maintain the ferry on the beach and can include the drag component of the current.

F_T = Thrust force developed by the propulsors at angle θ with the centerline.

M = Steering moment additionally developed by multiple thrusters.

F_s = Lateral reaction at the shore, which is eliminated in the development of the solution.

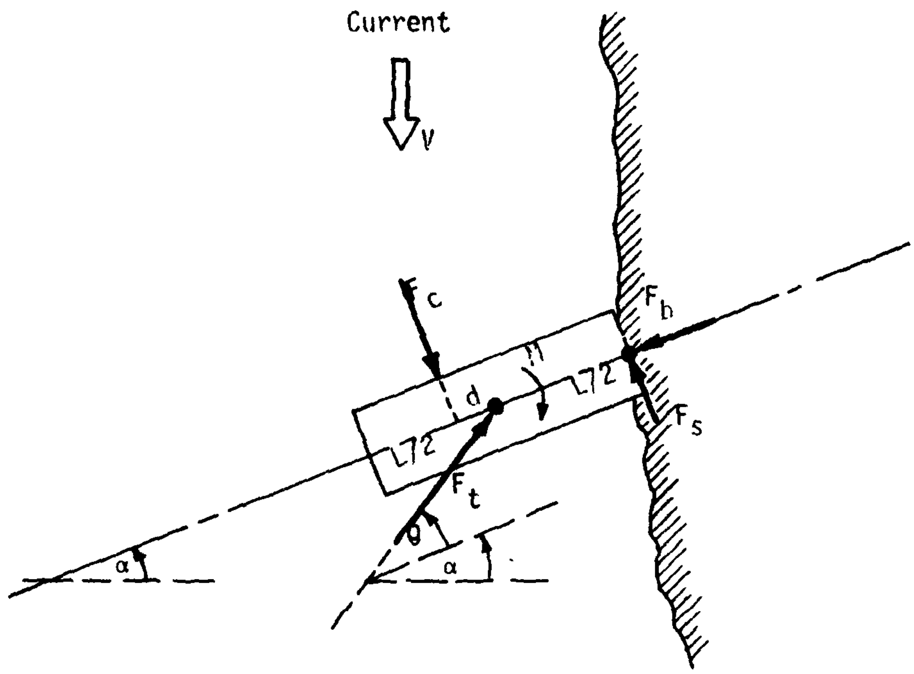
d = Distance from midships at which F_c is effective and which depends on current velocity gradients and shape of the ferry.

L = Waterline length.

α = Angle of the ferry's centerline to a shore reference and which is the <u>only measured variable during the beaching.</u>

g = Constant for current drag on hull.

The solution is a steady-state solution, and when a restoring force (or moment) is added the dynamics of the situation must be examined to ensure a stable system with appropriate natural frequency. The restoring force must be a variable with the angle, α, and several ways of generating this force can be examined.



Equations:

(1) $F_c = f \cos^2\alpha$ where $f = f[V^2, L, \text{draft}, \text{Drag coefficient}]$

(2) $M_{bow} = F_c(L/2 + d) + (L/2)\, F_t \sin\alpha + M = 0$

(3) $M_{CG} = F_c\, d + F_s\, L/2 + M = 0$

(4) Along Centerline: $F_t \cos\theta + F_b = 0$

(5) On the Beam: $F_c + F_t \sin\theta + F_s = 0$

where:

F_t = controllable thruster force
F_b = required beaching force
M = controllable thruster moment
F_s = variable force at grounded bow

FIGURE 19. FORCES ON A BEACHED FERRY

Moment equations can be developed to give the following form:

$$M = (f \cos^2\alpha) \quad (L/2 - d) \quad - \quad (F_b + g \sin^2\alpha) \quad L/2 \quad \tan\alpha$$

If the solution is given the assumption that the principal loading force (or moment) derived from the term "$f \cos^2\alpha$" is larger than it really is, the computations for F_T, θ and M will adjust themselves accordingly. One method for inserting a restoring force and moment is to substitute ($f \cos^2 \alpha + f' \sin\alpha$) wherever the term ($f \cos^2\alpha$) appears. At $\alpha = 0°$ the restoring force becomes zero whereas the loading force is maximum. At $\alpha = 90°$ the loading force is zero and the restoring force is maximum.

An on-board processor program to use such a formulation can be developed. The constants in the formulation will vary with ferry loading and draft, and with current profiles in the immediate area of the beach position. Basically, such constants for a craft are determined from model tests. The integration of the changes in these values during a single beaching presents some difficulty in the development of the system.

As a vehicle disembarks, the operator in the vehicle or the remote controller would switch the control system into this "holding" mode. When the ferry is ready to retract and depart, the control system is switched back to the transit mode by the remote controller.

4.4.5 Automatic Navigation

Automatic navigation of at least the empty return trip is an alternative to a remote human pilot. As will be discussed elsewhere, this mode has not been selected for the most promising baseline RPAR system. However, in principle, the on-board computer could operate on data obtained from a homing beacon receiver or a precision navigational beam system to control the path of the raft along a pre-programmed trajectory. This would complicate the function of the controller considerably and would require a much more complex and costly computer on-board the raft.

4.4.6 Controller Hardware

As noted earlier, the central controller and signal conditioning system is, in essence, a special purpose microcomputer which must be designed around available microelectronics. It will likely contain several microprocessors, programmable memory, and other electronic logic and data handling components. The hardware is viewed as relatively straightforward and of modest cost. Initially, however, the programming and preparation of the accompanying software will be complex and time-consuming.

4.4.7 Drive Electronics

The electromechanical drives required to control throttle, thruster direction, etc., will require, in turn power amplifiers which operate in response to the low-power signals from the command computer. Again, this is well-developed technology, whether electrical servos or electrohydraulic servos are used for the actual output. In general, it is possible to purchase and adapt standard electronic systems for this type of function.

4.5 NAVIGATIONAL SYSTEMS

4.5.1 Introduction

As noted in Section 2.5.3, the two promising candidate approaches for the RPAR are:

(a) Remote human pilot for both forward and return passages, and

(b) Human pilot on the vehicle for forward passage and automatic return passage.

This section discusses the navigational systems and equipment required to implement these approaches.

4.5.2 Automatic Navigation Systems

In most instances the ferry can and is desired to cross the waterway in a straight line, but instances will occur where obstructions are situated between departure point and landing point. The navigation system should be able to control the path of the ferry in addition to the end points of the trajectory.

Three principal automatic guidance systems have been used; the "homing" and "beam-riding systems" are described in Appendix C. These two systems have several disadvantages for use with the ferry:

1) There is no direct control over the path between departure and landing points.

2) The sensors and processors on board the ferry become complex and expensive.

3) Beacons are required on shore and these in themselves increase vulnerability of the system.

The third group of systems is comprised of direct optical triangulation or electronic hyperbolic systems (such DECCA, LORAN C and similar precision systems of shorter range). These systems provide information on the position of the target. This information is compared to the intended position, and this feedback is translated first into corrected course and speed requirements and then transformed into instruction to the thrusters. These systems have the disadvantages of:

(a) Complex processors on board, and
(b) At least two accurately placed stations along the shoreline.

This discussion shows that there are obvious disadvantages to all of the systems that can be used to implement the automatic return passage where the forward passage is controlled by an operator on the vehicle being transported.

It will be recalled that the closed-loop programmed path which requires a position feedback system of the type discussed above has dubious operational advantages because it will probably not eliminate the need for an on-shore operator for programming.

Thus, the simplest and most promising of the automatic systems is probably the homing system, despite the fact that it carries several major disadvantages with it.

For these reasons, the use of remotely piloted control was selected as the baseline RPAR system. The navigational feedback information for a remote pilot will be discussed in the following subsection.

4.5.3 Remote Pilot Feedback

In the remotely piloted system, position and course information are registered at a shore location. The corrective control actions are then taken by the pilot through a communications system or data-link to the on-board controller.

The primary methods for supplying navigational data to the remote pilot are as follows:

(a) Visual (naked eye or infra-red).
(b) Positional data via electronic hyperbolic systems as discussed in the preceding section.
(c) Radar.
(d) Directional Gyro with telemetered data.

System (b) suffers from the disadvantage that it needs two accurately spaced stations along the shoreline. On the other hand, the pilot obviates the need for a complex processor and the system is clearly feasible. It is felt, however, that the same information can be obtained more simply and in more convenient form by means of a radar system.

Thus, this subsection discusses (a), (c), and (d) above as the primary promising methods for supplying positional information on the raft.

(a) Visual Feedback

Most aircraft pilots flying in clear weather at low altitudes and modest speeds prefer to fly under Visual Flight Rules (VFR) rather than Instrument Flight Rules (IFR). This is especially true during the landing approach with its relatively precise and exacting control requirements. The reason for this is that the human vision system provides a tremendous depth and width of field, depth or distance perception, and instantaneous data processing and interpretation. No artificial navigational or attitude sensing system can approach the capabilities of human vision when the field of view lies within the human field of vision.

Thus, it is clear that, in cases when the human pilot has a clear view of the RPAR and the crossing area, he will likely rely on his vision for feedback, even if he has a navigational position and course measuring system at his disposal.

The visual feedback, then, must be regarded as a primary component of the system and the navigationl system as an aid to be used primarily at night or under poor visibility conditions.

(b) Radar

The remote pilot concept and the need for all-weather capabilities results in the requirement for remote reporting of the location and orientation of the ferry to the remote pilot. The requirements for location data can most readily be served by a short-range radar. There exists a wide choice of commercial marine radars, some of which appear to be well suited to the task. No breakthroughs are required in radar performance; rather, one can choose from a number of commercially available, field-proven radars, several of which appear to have performance that matches the needs.

The system will probably use the operator of the vehicle being transported to guide the final far-shore landing, so that accuracies greater than a few meters are not required. Rather, we can deal with accuracies of 10 to 25 meters for the radar. Thus, the range accuracy should be of this order, and the angular accuracy should correspond to this uncertainty at the far-shore distance from the radar.

Many marine radars provide this performance. For example, the 50-nanosecond transmitted pulse available on some of the radar sets corresponds to a range resolution of 7.5 meters, well within the requirements, particularly as range accuracy is not needed to this value. Range resolution is desirable to this value because the far shore will be shown on the radar screen. It is at this critical point that accuracy becomes important.

A typical river width for this application is estimated to be 150 to 200 meters, and, at that range, one-tenth radian (5.7°) or angular accuracy corresponds to 15 meters, well within the capability of many of the available marine radars. These systems typically have angular resolutions of two to five degrees, largely dependent on antenna length.

In actual use, the radar antenna would be installed at a moderate distance from the near-shore embarkation point to avoid the clutter and loss of detail associated with radar responses very near the radar antenna.

In use, the operator will perform his remote control function using the Plan Position Indicator (PPI) display of the radar set. This presentation would show both the near and far shores, as well as the position of the ferry itself as it traverses the river. The operator will adjust his thrust direction and magnitude to make the target on the radar presentation approximately follow the desired route from the near shore to the far shore. This route could even be crayoned in on the front surface of the radar indicator. The operator will have to make use of the ancillary information concerning the heading of the ferry itself, which could be presented on an indicating meter or a digital display attached to the PPI indicator. Using this information, the remote operator can control the ferry to traverse the required path, including the avoidance of obstacles in the river, which can also be shown on the display. As the ferry approaches the far shore, the operator would be guided by a vehicle crew member on the ferry using the vehicle radio as a communication link.

Some improvements to the display for the remote operator could readily be made by taking advantage of recent developments in data manipulation and display. For example, the raw data from the radar set (PPI) could be processed to provide the display to the operator so that the shore lines are shown in a different color from the position of the ferry. The ferry's orientation could be shown on such a display by the representation of a small vessel with a bow and a stern. The record of the successive positions of the ferry could be tracked in the system and shown as a lighter dotted line. Thus, the remote pilot could make use of the previous history of the traverse rather than the instantaneous value of the position only. Such a display system presents the data to the operator in an "electronic game" format which might be more suitable than the raw PPI of the radar set. The processing could also include estimated time to arrival at the far shore or a presentation of the actual speed over the bottom of the river, thus making the remote pilot's task easier to accomplish.

(c) Directional Gyro

As discussed in the preceding paragraphs, a radar is the most promising position tracking system under conditions of poor visibility. This system, of course, only provides the remote pilot with a blip or target showing the position of the ferry; it does not show the heading of the craft's centerline. The latter information is critical in order for the pilot to effect thrust direction changes for course correction. Thus, an additional navigational aid is required for this purpose.

The conventional aircraft instrument for this purpose is a directional gyrocompass. A gyro is driven pneumatically or electrically and brought up to speed while the craft is stationary. The indicator or card is then rotated so that it lines up with the known heading of the craft's centerline.

From this point on, so long as the gyro continues to rotate at speed, the indicator, which is fixed to the craft, shows the heading relative to the gyro which is fixed in space.

If an angular resolver is fixed to the gyroscope cage, a signal is produced proportional to the heading of the craft. This signal can be telemetered to a remote pilot station indicator. Alternatively, it could be used as a feedback signal for the auto-pilot holding function provided by the on-board control processor. Finally, the telemetered signal could be used by the PPI radar display processor to display a representative vessel on the screen of an improved electronic game display format as discussed in preceding paragraphs.

Directional gyros with axis angle resolvers are conventional aircraft instruments and are available from several sources. Thus, specific vendors and their specifications have not been investigated in detail. Performance specifications are set by the Federal Aviation Administration and the Defense Department for the available instruments.

In the RPAR system, the actual gyro would be mounted in a panel included as part of the emergency on-board control station along with the on-board controller and communications system.

4.5.4 Remote Pilot Display and Control Panel

The discussion in the preceding subsections can be used as a basis for a preliminary development of the likely remote pilot display and control panel. The displayed data and controls will include:

(a) The position radar on a screen.

(b) Thrust directional controls--probably a pair of joysticks or one joystick and a moment control wheel (for the split mode).

(c) Engine status monitors and starting controls.

(d) Ramp status monitors and starting controls.

(e) Auto-pilot holding function control.

(f) Directional gyro display.

A conceptual layout for the remote pilot panel is shown in Figure 20. This is not intended, of course, to be accurate at this point, but, rather, simply shows the type of controls envisioned for a remote pilot.

4.6 COMMUNICATIONS

4.6.1 Introduction

The communications links between the various components of the RPAR system will be a vital part of the system. Three distinct communication channels are required to provide control of the ferry by a remote pilot. These channels are:

(a) Two-way voice between the vehicle personnel and the remote pilot.

(b) One-way command channel from the remote pilot to the ferry.

(c) A navigation-data channel from the ferry to the remote pilot.

The major requirements and factors affecting these channels are discussed in the following subsections.

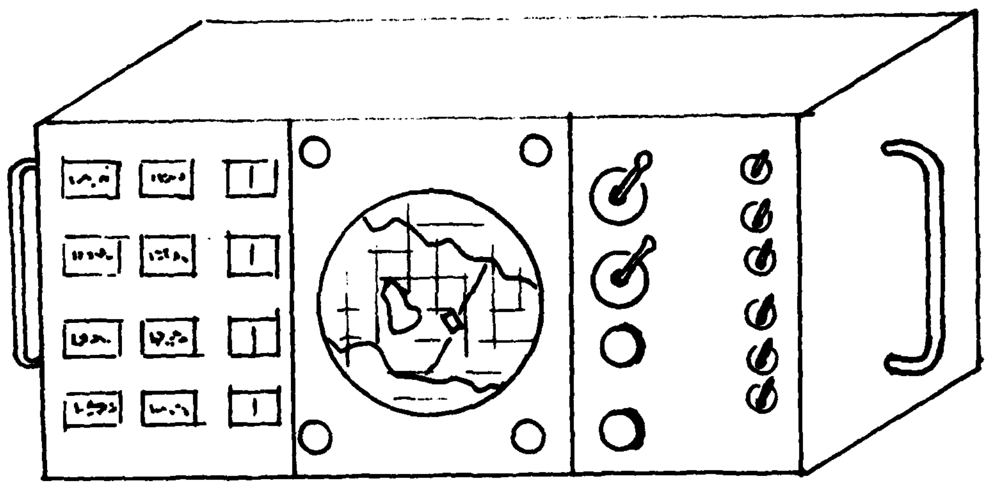


FIGURE 20. CONCEPTUAL LAYOUT FOR A PORTABLE REMOTE PILOT PANEL

4.6.2 Two-Way Voice Channel

It is anticipated that the primary use of this voice channel between the vehicle personnel and the remote pilot will be to allow the vehicle personnel to augment the navigational information available to the pilot from his own vision and from the navigational aids. This is expected to be most important as the craft approaches the far shore.

The individual in the vehicle with the best forward vision would guide the approach and docking procedure via the voice channel. In the case of a tank, the findings discussed in Section 3 indicate that this will be the tank commander. An alternative to the use of the voice link for this purpose, of course, would be for the tank commander to directly control the RPAR approach and landing process by means of a control box in the tank communicating with the RPAR controller via an umbilical cord or on the command radio channel. Further system development and testing will be required to determine which of these options is preferable.

In any case, it will be necessary to provide the voice channel so that clear transfer of control can be effected and command decisions can be communicated.

It is likely that this channel can make use of the available tank radio communication equipment. The remote pilot would be equipped with a headset and a tank radio to provide this capability. This communication channel is deemed necessary because a surveillance radar for control of most of the river crossings may be inadequate to provide the fine detail at the far shore required for the docking. As it is envisioned, the tank personnel will provide up-to-date information on control as the ferry approaches to within about 50 yards of the shore. By this means, the tank personnel will note such requirements as a few yards' correction to the exact landing place, corrections to the orientation of the ferry, minor corrections to speed, required compensation for river currents, ramp release time, etc.

4.6.3 One-Way Command Channel

This channel provides the remote pilot or tank commander with the capability of controlling the ferry motion. This control is effected by three main controls:

(a) Control of the direction of the thrust for each thruster.

(b) Control of the amount of thrust (i.e., engine throttle setting for each engine).

(c) Lowering and raising the landing ramp.

The control of thrust level and direction will be in response to map or radar coordinates Several configurations of operator (pilot) controls are possible, but all accomplish the same thing, and each of these control signals must be transmitted to the ferry. Digital data transmission is envisioned for accuracy and to make jamming more difficult. The recommended method is to use low-frequency inductive signaling on a carrier below 20 kHz. Ten-bit accuracy is more than adequate for this purpose, and if the transmitted data are updated five times per second, the basic data rate is only 150 bits per second, thus requiring only a small bandwidth, even with redundancy and framing requirements.

The advantage of a low-frequency inductive radio link is the rapid falloff of signal with distance, thus providing some security of transmission and making it difficult to jam. Alternatively, a tank radio could be used for this purpose with an audio tone coder and audio tone decoder added to the standard tank radio.

4.6.4 Navigation Channel

The flexibility of the propulsor system for powering and controlling the ferry and the desire to make the remote pilot's task simple and easy to accomplish, together with the requirement that the ferry orientation be known by the remote pilot, requires that the ferry orientation be determined. The simplest way of providing this information to the remote pilot is to telemeter this data to the remote pilot's console.

A radio link is planned for this purpose. Several samples per second of the output of an appropriate gyro compass with resolution of 10 bits is adequate for this purpose. Thus, only a small bandwidth is required. Again, a low-frequency inductive radio system can be used to advantage.

In addition, this channel can be used for sampling and displaying several other system status conditions. For example, engine temperature, oil pressure, RPM, and ramp positions could be periodically sampled and transmitted to the remote pilot via this channel.

4.6.5 Findings

The two-way voice channel requirements can readily be met by the use of the tank radio and a corresponding radio at the remote pilot's console.

Low-frequency inductive radios meet the requirements for the command channel and the navigation channel. Such radios will require custom design, but the requirements can readily be met with quite modest equipment. Alternatively, the command and telemetry data could be superimposed on the voice communication radio by means of audio tone coding or a separate conventional radio channel could be allocated for the purpose.

5. DESCRIPTION AND FEASIBILITY ASSESSMENT OF THE BASELINE CONCEPT

5.1 INTRODUCTION

The studies reported in the preceding sections of this report have provided a basis upon which to select the most promising RPAR system concept. This baseline concept is summarized in Table 8. An artist's drawing of the system in operation is shown in Figure 21. A brief recapitualation of the baseline characteristics of each major subsystem and the significant alternatives is given the following subsections.

In general, it can be stated that each of the subsystems have been examined to sufficient depth to demonstrate the feasibility of the concept. Although these examinations constitute a preliminary optimization of the system, they do not address all of the design problems which will arise and will later affect the final configuration. The components which have been assumed have been selected conservatively and all will be within the current *state-of-the-art*. The configuration is based upon existing and available equipment and materials.

5.2 THE RAFT HULL

The baseline hull design is capable of operating independently to transport loads to MLC-35. Two of these baseline hulls can be connected together and operated as a unit to transport loads up to MLC-70. An artist's rendition of single section carrying a light tank is shown in Figure 22. Each hull section is 28 feet long, 20 feet wide, and 4 feet deep. The loaded draft is calculated to be 3 feet, leaving a freeboard of 1 foot.

TABLE 8. BASELINE RPAR SYSTEM

- 2 hull sections (one for M-3, two for M-1).
- 2 jet type propulsors per section.
- On-board data processor.
- Remote control by near-shore pilot with dual capability on vehicle and raft.
- Voice link with vehicle.
- Navigational information by radar and telemetered from on-board directional gyro.
- Tank commander directs the far-shore docking by voice or dual control box.
- On-board processor automatically holds raft on shore (auto pilot function).
- Return to near-shore by near-shore pilot.

FIGURE 21. THE BASELINE RPAR SYSTEM IN OPERATION

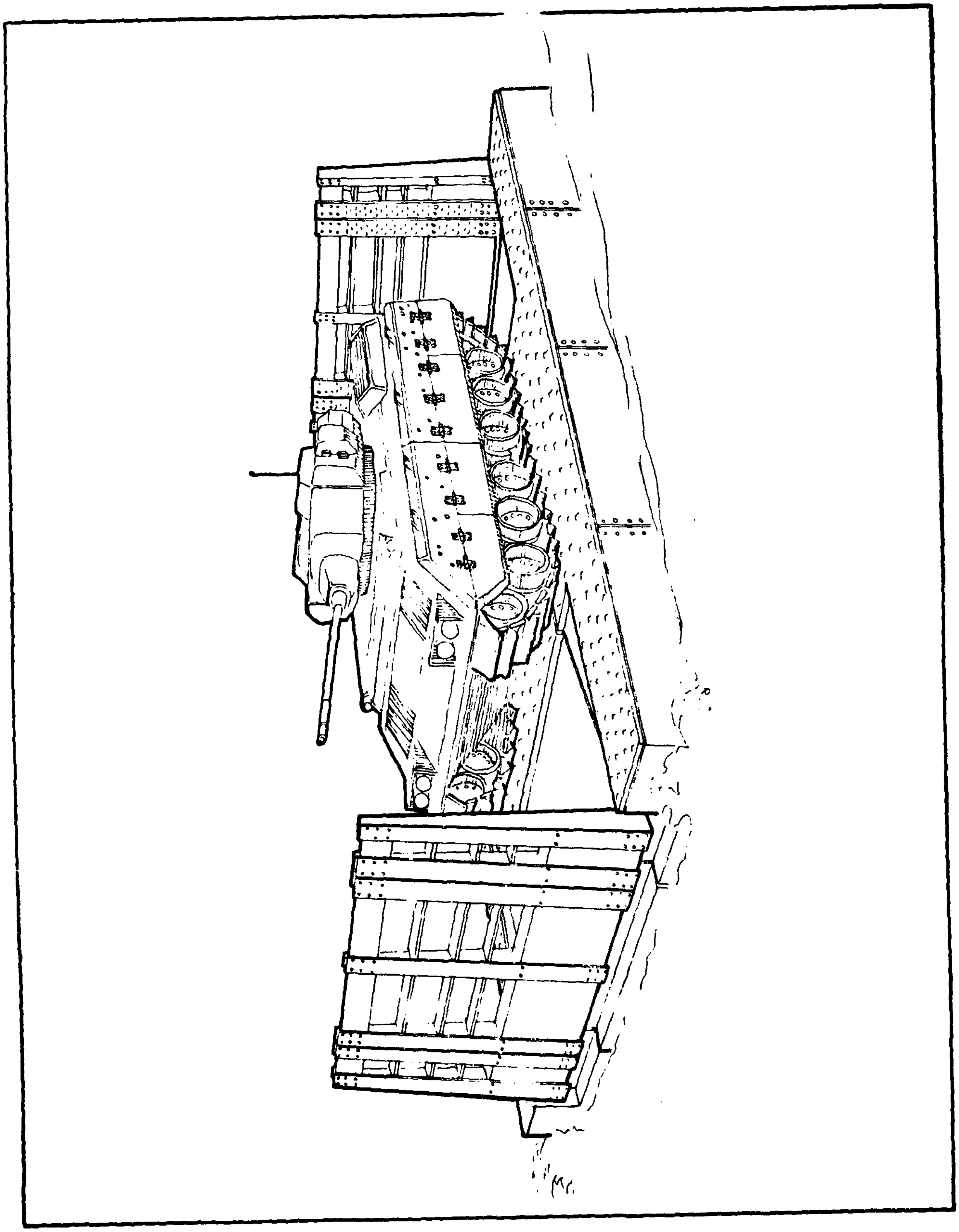


FIGURE 22. A SINGLE RPAR SECTION IN OPERATION

The baseline construction of the hull would consist of fabricated and welded steel and aluminum structural members similar to current and proposed military bridge units. However, reinforced plastics and composite materials should be examined as low-weight alternatives.

To provide roadability when transported by carrier vehicle or trailer, each hull section should be hinged to allow the folding of two 5-ft wide wing sections so that the stowed cross section of the hull will be 10 ft wide x 8 ft high.

A 10-ft long ramp would be located on each end of the single hull bay. It would occupy the full 10-ft width of the center section. Two 2-ft wing ramps attached to the wing sections would be used to accommodate wider vehicle tracks.

The propulsion units and control hardware would be located below deck in the center compartment of the hull which measures 16 ft long x 10 ft wide x 4 ft deep. This space would be compartmentalized by a watertight bulkhead athwartships as a minimum, and possibly, fore-and-aft as well. The ends of the center section and the wing sections would be foamed for survivability.

Deployment, launch, retrieval and stowage of the raft have been studied and found to be practicable for the baseline concept. A variety of design alternatives remain but basic feasibility seems assured.

5.3 PROPULSION

Each hull section would be powered by two pump-jet thrusters of the Schottel-type. The appropriate size is the Schottel SPJ-50 which produces 2250 lbs of thrust at maximum speed. For continuous operation at this thrust level, an engine rated at 160 hp at 2300 rpm is needed. A diesel engine is the optimum prime mover and an air-cooled diesel is expected to provide maximum weight and maximum reliability and maintainability. An appropriate selection is the Deutz Model F8L413 which is a V-8 engine, Again, the use of available components provides a conservative baseline for which feasibility is assured. It would be prudent, however, to examine alternative designs in the detailed design phase. For example, one such alternative would be the substitution of a conventional stationary centrifugal pump and a 360° rotatable nozzle for the Schottel pump-jet unit. Such a steering nozzle, of course, would require development but may provide reliability and procurement advantages.

5.4 ON-BOARD PROCESSOR

The on-board processor is the key component in the control system. It is essentially a special purpose mini-computer capable of translating command signals from the command radio link into appropriate thruster and engine adjustments to achieve the desired results. This on-board processor will also handle all of the controlling data for the engines and ramps from the pilot and all of the engine condition and directional gyro data to be telemetered to the remote pilot.

Additionally, the on-board processor will contain the logic required to act directly on the gyro feedback signal to control the thrusters and engines and provide an autopilot shore-holding function during the loading and unloading phase of operation. This automatic mode would be initiated by the pilot following the docking maneuver, and would be manually terminated when he is ready to traverse the river again.

The physical equations which govern these functions are straightforward, and present no problem. Complexity arises in the programming for the various modes of operation of the ferry, integration of sensor inputs such as those from a directional gyroscope, and ensuring the capability of the system to adapt to varying conditions such as a ferry draft or propulsion casualties. The control system is based upon existing technology. The central relationships are known although the magnitude and behavior of some of the constants are peculiar to hull shape and must be determined by model towing tank test. Software development is expected to be a most arduous procedure, but completely feasible.

5.5 NAVIGATIONAL SYSTEM

The primary navigational feedback to the remote pilot will be visual. He will control the passage of the RPAR across the river in response to this visual feedback. It is anticipated that as the far-shore docking phase is approached, the vehicle commander will provide more detailed information, with his better view, via a voice radio link.

However, at night or in periods of poor visibility the remote pilot will require navigational aids. The baseline navigational system consists of a short-range PPI radar on which he can follow the progress of the raft across the river and a directional gyro on-board the raft which will telemeter the raft centerline heading back to the remote pilot.

Again, all of the navigational hardware is based on available components or well-proven processes. Although, changes will undoubtedly be required for specific RPAR conditions and requirements, the system should be completely feasible.

5.6 COMMUNICATIONS

The system will require voice communications between the remote pilot and the vehicle, probably using the conventional tank radio. In addition, the on-board processor will be controlled by the remote pilot via a command channel and the various data from the processor will be telemetered back to the pilot via a navigation channel. The most promising concept for these control channels is low-frequency inductive transmission below 20 kHz. This will minimize the possibility of interference or jamming.

Although custom design of a low-frequency system would be required, it is well based on existing art and should present no obstacles to feasibility. In any event, several alternative methods are available which would use available communications equipment.

5.7 RISKS

Although the overall RPAR concept appears to be feasible, any new design includes some development risk. In particular, a concept which has to meet the many interrelated requirements such as are demanded of the RPAR can encounter difficulties if any one critical aspect fails to come up to expectations. The following paragraphs note the areas where such risks may be anticipated.

5.7.1 Structure

The development has assumed a type of construction similar to current bridge and floating equipment practice. The weight of the units and its damage resistances are critical. Composite construction and use of plastics and materials other than steel and aluminum may provide a better combination of weight and strength characteristics. Unless the performance of such materials under the conditions for ferry operation are fully established prior to actual design, some risk would be involved in their use.

5.7.2 Propulsion

The propulsion equipment (air-cooled diesels in the 150- to 180- BHP range and the SPJ-50 unit) is of established performance and reliability. Sufficient space and weight allowance is available for their use. Smaller units would permit lesser ferry weight and greater reserve buoyancy. The possible alternative of an internal centrifugal pump discharging through a steerable nozzle in the bottom of the hull has greater risk inasmuch as the system composed of prime mover, pump, and nozzle must be assembled to work together in the necessary power range. That is, a new three-component system must be developed in lieu of a two-component system using proven components.

5.7.3 Raft

It is apparent that rafting capability is sensitive to total weight and configuration. As the entire ferry system design process proceeds toward specific values, the handling system possibilities will emerge with increased clarity. Existing experience with handling systems for pontoons, boats, and bridges establishes a sound precedent. Nevertheless, until the dynamic behavior of this new unit is examined, some risk remains in design of the handling (unfolding, launching, retrieval, and collapsing) phases of the ferry cycle.

5.7.4 On-Board Control

The automated control of multiple-unit systems has been accomplished successfully in aerospace, industrial and weapons applications. No factors have been identified in the ferry system which would prevent similar achievements. The development and design effort required may be large, but the risk of an unsuccessful outcome is very small.

5.7.5 Remote Pilot Control

The remote pilot control station essentially consists of an assembly of components and hardware firmly based on the existing state-of-the-art. Thus, there are few unknowns concerning the expected performance of the hardware. Instead, the primary risk is associated with the human operator interface and the achievement of a design that permits the operator to perform the required raft control functions.

5.7.6 Transport

Maximum unit weight and dimensions are critically affected by mobility requirements, and vice versa. Some development risk exists in that an RPAR unit designed to meet operational requirements may result in a size which reduces its mobility, or conversely that adherence to mobility requirements reduces the operational capabilities of the unit. At this stage, it is not possible to fully evaluate this risk. The concept described in this report appears to meet both sets of opposing requirements. Inevitable modifications during the design phase may affect this balance.

5.7.7 Operational Risk

The risk level of mission accomplishment is composed of several factors such as:

(1) The reliability of the mechanical, electric, hydraulic, and electronic components in the system.

(2) The competence of the control system to handle the various modes of ferry operation and environmental conditions as well as contingencies.

(3) The physical damage resistance of the system, or conversely its vulnerability, to natural events or enemy action.

(4) The probability of occurrence of conditions outside of those specified in the design, such as shore configuration, current speed, etc.

Reliability can be approximated from statistical evidence for similar components and subsystems. As has been noted repeatedly, all components are, or are similar to, state-of-the-art items.

Control system capability is more complex and some unknowns remain at this time. For example, in many situations the shore-based remote pilot will be able to rely upon direct visual surveillance, plus radar image, to provide himself with ferry position information. In other situations he will have to rely solely upon radar information. The degradation, if any of control performance in the latter case cannot be evaluated here.

Another example relating to control is the risk existing in the capability of the operator to cope with the finer points of ferry navigation. We cite the experience with a design for a 4-propulsor catamaran ferry reported in a recent technical publication.* Experience with fully rotatable propulsors had alerted the owners to the need for crew training. For this catamaran ferry, the forward pair and the after pair of propulsors were ganged and each set was controlled by a lever, one in each hand of the ferry master. For several reasons an 1/8 scale model was built to serve as training simulator. Masters were given five-day training sessions including at least eight hours afloat at the controls. Learning to control the craft with various numbers and combinations of propulsors operable was an important part of this training.

As to damage resistance, the ferry can readily be designed to withstand normal shore and bottom contacts, but the vulnerability to enemy action is high even if the ferry as a whole can be built to withstand total flooding.

As to the fourth factor, it is understood that the system requirements are based on analyses of the probable areas of operation. The specification implicitly accepts a risk of reduced effectiveness when the ferry is used in areas with other, or more stringent, typical characteristics.

In summary of this operational risk aspect, it would seem a most appropriate course of action to construct a test-bed, either full-scale or to a smaller scale, in which both the components of the system as well as entire system can be tested for operational performance. Most of the risks cited in this section of this report can be reduced to small proportions, if not removed entirely, by such a procedure. The control system development would be that of the full-scale system, but the costs of the design would be reduced and the risks largely removed before a full-scale system were entered upon.

*"The Sea Bus Story," John Nelson Case; Marine Technology Volume 18, No. 4, October 1981, Society of Naval Architects and Marine Engineers.

6. SYSTEM R&D AND ACQUISITION COST ESTIMATES

6.1 INTRODUCTION

The research and development cost estimates for the RPAR were made by Arthur D. Little, Inc., based on conservative research, development and engineering practices. These cost estimates include only the estimated contract effort that will be required for a 6.3 Validation and Demonstration. Accompanying in-house Government monitoring and technical effort is not included, nor are Government testing costs. The acquisition cost estimates were based, wherever possible, on current, or potential suppliers. Where necessary, estimates were made by Arthur D. Little, Inc., based on conservative engineering and manufacturing practices. It is assumed the RPAR system consists of the following modules:

- Two MLC 35 self-propelled rafts.
- Two RPAR trailers (16-ST rough terrain capacity) equipped with launch and recovery submodule.

We have assumed that the acquisition lot size would be five complete RPAR systems. We have not included as part of the system cost the prime mover required for towing the RPAR trailer. We are assuming the prime mover will be an armored vehicle integral to the assault force including the M9 tractor as a potential engineer armored support vehicle, or the M728 combat engineer.

6.2 RESEARCH AND DEVELOPMENT COST ESTIMATES FOR THE PROTOTYPE RPAR SYSTEM

The research and development costs for RPAR system have been estimated by Arthur D. Little, Inc., and are presented in two parts—the electronics for the command and control subsystems, and the mechanical modules for the RPAR MLC 35 unit and the RPAR trailer. The research and development costs were estimated on a conservative basis and include the contractor effort for preliminary design and the building and testing of an experimental model for proving feasibility in the case of the electronic subsystems. For the mechanical modules, a design program as well as the prototype development is included. Accompanying Government monitoring and technical costs are not included.

The cost for the electronic command and control subsystems is $1,500,000 and $1,155,000 for the mechanical modules for a system grand total of $2,655,000. A more detailed research and development cost is presented in Table 9.

The foregoing research and development cost estimates include development engineering, producibility engineering and planning, prototype manufacture, and contractor testing during development, but they do not include tooling, system test and evaluation by the Government, training, or facilities required for Government testing.

6.3 ACQUISITION COST ESTIMATES

The acquisition cost estimates are arbitrarily based on system lots of five. The system lot of five would include ten on-board command and control subsystems, five remote pilot station subsystems, ten RPAR MLC 35 units, and ten RPAR trailers.

The estimated cost of the RPAR MLC 35 units, which can act as a stand-alone ferry for MLC 35 vehicles and lower, or can combine with an additional MLC 35 unit and can act as a heavy ferry for MLC 70 vehicles, approximates $213,900 in small quantities. The cost estimate is presented in Table 10. The estimated cost of the RPAR trailer, which has a capacity of 16 ST and will carry one RPAR unit, is $80,000. This estimate is based on a recent quotation for a standard trailer by Eidel, and the cost estimate is calculated based on a formula provided by Eidel. The cost estimate is presented in Table 11. The cost estimate for the RPAR high mobility pilot station approximates $29,900 and is presented in Table 12.

TABLE 9. RPAR RESEARCH AND DEVELOPMENT COST ESTIMATE

	Preliminary Design, Experimental Model, Test to Prove Feasibility (FY1982 $ 000)	Prototype Development (FY1982 $ 000)
Electronics for Command & Control Subsystems		
On Board Command & Control Subsystem		
Processor, Control Converter, Display, Manual Control Station, Communication Data Link	500	250 (2 subsystems)
Remote Pilot Station		
Radar, Control Console, Display Module Communication Data Link	550	200 (1 subsystem)
Electronic Subtotal	1,050	450
Mechanical Modules	Design	Prototype Development
RPAR MLC 35 Unit	400	500 (2 units)
RPAR Trailer	75	180 (2 units)
Mechanical Subtotal	475	680
System Total	1,525	1,130
Grand Total		2,655

TABLE 10. ESTIMATED COST OF RPAR MLC 35 UNIT (35 FT x 20 FT x 4 FT)

Subsystem Module or Item	Description or Quantity	Unit Cost ($)	Cost (FY1982 $)
Structure	14 ST	5,000/ST	70,000
Hinges: Soss Type	32 ft		5,500
Hydraulics	Entire system		4,600
Controls	Propulsor only		5,700
Auxiliary Equipment	Fuel tanks compressor and ventilation subsystem, bilge pump, covers, hoists, compartments for electronics		9,200
Propulsion Subsystem:			
Deutz Diesel	2 150 BHP w/aux.	100/BHP	30,000
Schottel Pump-Jet	2 SPJ	12,000	24,000
On Board Electronics			37,000
	Navigation controller	2,000	
	Data processor & command computer	15,000	
	Sensor processor	3,000	
	Control converter	3,000	
	Display	3,000	
	Manual control station	8,000	
	Communication data link	3,000	
Total Unit Cost			186,000
Tooling, manufacturing design and engineering		5%	9,300
Profit and taxes		10%	18,600
Expected price			213,900

TABLE 11. ESTIMATED COST OF RPAR TRAILER BASED ON EIDEL FORMULA

Cost estimate is based on the following Eidel budget quotation for rough terrain trailer.

Standard 6 ST payload trailer is \$48,000. Additional payload directly affects only 40% of standard cost.

A 16 ST rough terrain trailer cost

$$= 48{,}000 \times .60 + 48{,}000 \times .40 \times \frac{16}{6}$$

$$= 28{,}800 + 51{,}200 = \$80{,}000$$

TABLE 12. ESTIMATED COST OF HIGH MOBILITY REMOTE PILOT STATION

Subsystem Module or Item	Description or Quantity	Unit Cost ($)	Cost (FY1982 $)
Remote Pilot Station Electronics	Radar System		15,000
	Basic radar	7,000	
	Modification to display track	5,000	
	Conversion to military usage	3,000	
	Command and Control Station		11,000
	Control	5,000	
	Display	3,000	
	Communication data link	3,000	
Total Unit Cost			26,000
Tooling, manufacturing design and engineering		5%	1,300
Profit and taxes		10%	2,600
Expected price			29,900

The total RPAR system cost consisting of two RPAR MLC 35 units, two RPAR trailers, and one RPAR high mobility pilot station approximates $618,000 The estimated system cost is presented in Table 13.

6.4 MULTIPLE PRODUCTION COSTS

It is expected that significant cost reductions can be accomplished by the Government's purchasing of multiple production units of the RPAR system. We have made the assumption that a production unit of the RPAR system is five systems. The production unit of five systems consists of:

- 10 RPAR MLC 35 units or bays,
- 10 RPAR trailers, and
- 5 mobile remote pilot stations.

It is assumed that there will be two sources of cost reduction. The first source is from an assumed learning curve relationship or production. The second source is from an investment in tooling which provides greater productivity. Thest two sources of manufacturing cost reduction are treated initially, individually and then in combination.

6.4.1 Learning Curve Cost Reductions

Utilizing past studies of ship and barge construction, the following learning curve constants were assumed for labor, material, and overhead, the three cost components of production. The cost segment breakdown and its respective learning curve constant are presented in Table 14. The

TABLE 13. RPAR SYSTEM COSTS IN SMALL QUANTITIES

Subsystem Module or Item	Description or Quantity	Unit Cost ($)	Cost (FY1982 $)
RPAR MLC 35 Unit	2 (36 ft x 20 ft x 4 ft)	213,900	427,800
RPAR Trailer	2 (16 ST capacity)	80,000	160,000
RPAR High Mobility Remote Pilot Station	1 (no vehicle included)	29,900	29,900
Expected price			617,700

TABLE 14. TABLE OF LEARNING CURVE CONSTANTS

Cost Segment, i	Cost Breakdown % C	Learning Curve Constant, a
Labor	30	0.990
Material	50	0.997
Overhead	20	9.982

$$C = \sum^{i} C_1 \times A_1^{n}$$

where

C = Decimal cost reduction for multiple production quantities

C_i = Cost segment breakdown %

A_i = Learning curve constant

n = Number of production units ordered

S_1 = 100 (1-C)

when

S_1 = Savings as % due to learning curve formula for the cost reduction expected from the learning curve is as follows:

$$C = \sum^{i} C_i \times A_i^{\,n}$$

where

C = Decimal cost reduction for multiple production quantities

C_i = Cost segment breakdown %

A_i = Learning curve constant

n = Number of production units ordered

The resulting savings expressed as a percentage is expressed in the following formula:

$$S_1 = 100\ (1-C)$$

where

S_1 = Savings as % resulting from learning curve experience

A sample calculation follows for a production order of five units:

$$C = \sum^{i} C_i \times A_i^{\,n} \qquad \%S = 100\ (1-C)$$

where $n = 5$

Labor

$$C_1 = 0.30 \times 0.990^5 = 0.2853$$

Material

$$C_m = 0.50 \times 0.997^5 = 0.4925$$

Overhead

$$C_o = 0.20 \times 0.982^5 = \underline{0.1826}$$

$$C = \quad 0.9604$$

$$S_1 = 100\ (1-C) = \quad 3.96\%$$

The decimal cost reduction and the corresponding savings as a percent is presented for four multiple production quantities. Table 15 shows that the savings are most significant for the larger production quantities.

6.4.2 Cost Reductions from Improvements in Productivity as a Result of Tooling Innovation

The manufacturing cost reduction that can result from facility and tooling innovation has been estimated for a varying number of production units under order in any contract. The basis of the potential savings is a factor b which represents the ratio of savings per unit of production that results from the investment in tooling, and this was assumed to be a factor of 0.10. In other words, the break-even point in production from the potential savings of tooling would be 10 units of production. It should be remembered that a unit of production has been defined as five RPAR systems.

The potential savings from improvements in productivity based upon facility and tooling innovation are defined by the formula:

$$S_t = C_t\ (bn-1)$$

It is important to again define the C_t which is the ratio of investment in tooling to the expected total control value. It was assumed in this study that the ratio of potential investment in tooling and facility improvement designed specifically for the production of RPAR systems was a factor of 0.05. We have provided a sample calculation illustrative of the formula for the potential in savings resulting from an investment in tooling.

$$S_t = C_t\ (bn-1)$$

TABLE 15. POTENTIAL SAVINGS IN MANUFACTURING MULTIPLE PRODUCTION UNITS BASED ON LEARNING CURVE THEORY

Production Units Ordered (n)	Decimal Cost Reduction (C)	% Savings (S)
5	0.9604	3.96
10	0.9233	7.67
20	0.8554	14.46
40	0.7408	25.92

where

S_t = Decimal savings resulting from investment in tooling

C_t = Ratio of investment in tooling to contract value = 0.05

b = Savings per unit of production resulting from investment in tooling = 0.10

n = Number of production units under order in contract

Sample calculation for n = 20

S_t = 0.05 (0.10 x 20 - 1) = 0.05

S_t = 5%

The potential savings in manufacturing of multiple quantities from improved productivity resulting from an investment in tooling are presented in Table 16. The quantities of production units were 5, 10, 20, and 40. Again, the table manifests the break even at a multiple production order of 10. The expected maximum savings that could be achieved would be at a production level of 40 production units ordered, and the potential saving from tooling would be 15%.

6.4.3 Potential Combined Savings from Multiple Production Quantities Ordered

Presented in Table 17 are the combined cost reduction and combined savings expected from both the savings resulting from learning curve experience and also from tooling investment. Again, the production units 5, 10, 20, and 40 are employed as the basis for comparison. It should be noted that the investment in tooling was based on a break-even point of a production quantity of 10 units. Hence, the production quantity of five units resulted in a lower combined saving in comparison with the saving for only the learning curve experience. The combined saving was only 1.56%. The combined savings for 20 and 40 production units ordered far exceeded the savings for only the learning curve experience. The combined savings for a quantity of 40 production units ordered approximated 37%.

TABLE 16. POTENTIAL SAVINGS IN MANUFACTURING MULTIPLE QUANTITIES FROM IMPROVED PRODUCTIVITY RESULTING FROM A FIXED INVESTMENT IN TOOLING

Production Units Ordered (n)	Decimal Cost Savings	% Savings (S_t)
5	-0.025	-2.5
10	0	0
20	0.05	5
40	0.15	15

TABLE 17. POTENTIAL COMBINED SAVINGS FROM LEARNING CURVE AND TOOLING INVESTMENT

Production Units Ordered (n)	Cost Reduction Learning Curve $(1 - S_l)$	Tooling $(1 - S_t)$	Combined Reduction	Combined Saving (S)
5 (25 systems)	(1 - 0.0396)	(1 - (- 0.025)	0.9844	1.56%
10 (50 systems)	(1 - 0.0767)	(1 - 0)	0.9233	7.67%
20 (100 systems)	(1 - 0.1446)	(1 - 0.0500)	0.8126	18.74%
40 (200 systems)	(1 - 0.2592	1 - 0.1500)	0.6297	37.03%

7. ANALYSIS OF MILITARY WORTH

7.1 INTRODUCTION

A quantitative analysis of military worth would require an extensive analysis of the capabilities of competing systems, including the proposed system concept, to satisfy the tactical requirements of a large number of scenarios. This type of extensive analysis is clearly beyond the scope of this study. Instead, the major features of the proposed RPAR concept have been compared with those of assault methods which do not provide the RPAR capabilities to obtain a qualitative evaluation of its military worth.

7.2 RIVER CROSSING DOCTRINE

Section 2.2 outlined the tactical situation likely to surround hasty crossings with reference to U.S. Army Field Manual No. 90-13. The important factors noted were the need to project combat power across a water obstacle without loss of momentum.

In particular, as described by FM 90-13, a river crossing is led by the assault forces that make the initial crossing and establish the security on the exit bank required to continue the crossing. The assault forces must close on the water obstacle and cross rapidly by any means available. Normally, these means include swimming, wading, pneumatic boats, and amphibious vehicles. Support from tanks can only be provided from overwatch positions since the support forces needed for conventional bridges or rafts can only be brought into play later in the assault phase.

As doctrine develops with an eye toward future conflicts, however, the need for hasty river assaults and crossings on a wide front is being increasingly stressed. In order to get firepower over to the exit bank quickly, this means getting tanks across early in the assault phase while there is still resistance from enemy units on the exit bank. Conventional crossing equipment would expose engineer support units to enemy fire while assembling and controlling conventional rafts or ferries.

This, then, is the context within which the military worth of the RPAR should be examined. There would appear to be two levels to the question:

(a) The military worth of a self-propelled assault raft; which is organic, rapidly deployable, but controlled by an on-board pilot.

(b) The relative increase in military worth afforded by the addition of a remote piloting capability to the concept.

7.3 MANNED ASSAULT RAFT

A manned assault raft concept is defined for this discussion as a system having all the attributes of the RPAR except that the raft would be controlled by an on-board operator. If the raft were subjected to the light enemy resistance to which the RPAR would be invulnerable, of course, the operator's station would have to be armored. However, it is assumed that, like the RPAR, the manned assault raft would be carrier or trailer transported by vehicles capable of keeping up with the armored units and that they would be assigned to these units to provide organic crossing capability. The raft operator would travel with the raft and no support engineer troops would be required to set up or mobilize the raft.

In the context of the river crossing doctrine summarized in the preceding section, there would appear to be no question that this type of assault raft would have considerable military worth. Instead of tanks supporting the initial assault troops from overwatch positions, the initial tank could be waterborne a few minutes after encountering the river and could be on the exit bank covering further assault operations a few minutes later.

Thus, it would appear that the basic concept of organic, self-powered, quickly deployable assault rafts has a high military worth.

7.4 REMOTELY-PILOTED ASSAULT RAFT

Adding the remote piloting feature to the assault raft does not decrease its military worth. The question becomes whether the increased capability increases the system worth over the manned version.

The remote-piloting feature with electronic navigational aids as proposed in this report enhances the pilot's capability in poor visibility. In addition, because it is likely to eliminate the need for an on-board operator, personnel vulnerability is reduced and survivability increased. These are seen as the principal factors leading to increased military worth.

7.4.1 RPAR Under Low Visibility

It is possible that hasty river crossings will be desired in dense fog or at night. In fact, FM 90-13 states that crossings may be planned for hours of darkness to reduce vulnerability and gain surprise over the enemy. Also, fact, the generation of smoke to cover such operations is commonly considered.

Under these conditions the RPAR with its instrument navigation system would clearly be superior to an on-board pilot limited to his own vision for navigation. Thus, the military worth of the RPAR is higher than the piloted version under that proportion of crossings conducted in low-visibility conditions.

7.4.2 RPAR in Normal Visibility

Because of the needs of transportability, size and launch/retrieval capabilities, the construction of any ferry of this type must be light, limiting the extent of defensive armor. Invulnerability of the ferry's propulsion plant can be achieved to small degree by its burial in the center of the entire structure, but multiple hits by projectiles above the .50-caliber or 20-mm range have the potential of disabling the power plant or the control system. Effective armor for the propulsion and control systems might add as much as 4 ST to the weight of the envisioned unit (MLC 35 capacity half ferry).

It is noteworthy that armor protection of the propulsion system is a matter of ferry survivability independent of whether the ferry is manned or unmanned. The critical elements of an automated or remote control system would be located within such an armored structure. On the other hand, separate armor protection of similar degree for a manned ferry operator might add an additional 1.5 ST. This 1.5 ST is the approximate net difference in weight between the manned and the unmanned version of the ferry.

In the event of attack by heavy weapons, either from shore or from the air, the vulnerability of the ferry is about the same whether it is manned or unmanned. The principal question becomes what an operator on-board can do which a remote control system cannot do, or vice versa.

On the initial crossing of the ferry (loaded with a vehicle) there exists the dual capability of remote or on-board control. The on-board controller is protected within the vehicle at a level equal to or greater than an on-board operator situated within a separate armored cubicle on the ferry. The communications, control and telemetry connections between ferry, vehicle, and shore, however, increase the vulnerability of the hardware and electronic system. The net effect may be either a loss or a gain. Presumably, one less person (the ferry operator) would be on-board in the automatic/remote control mode. The navigational risks, such as running aground or beaching inaccurately, are expected to be similar in both modes.

On the empty return crossing the vulnerability of the hardware and electronics may be compared directly to the vulnerability of an on-board operator. If both are protected to the same degree by armor, the penalty for the manned operation is some 1.5 ST plus the exposure of at least one person on-board. For this purpose of this comparison, the near-shore control personnel for the remote control mode are not considered vulnerable.

In regard to engine operation, a single operator on board has no capability for underway repair of malfunctions or damage since he would be fully occupied otherwise. Furthermore, quick access to the ferry hull interior underway is expected to be difficult. Multiple propulsors diminish the risks from engine casualties in either mode. The capability of one operator in regard to other forms of damage to the ferry likewise is small. Since the crossings are expected to be of short duration, any repair or adjustment must be accomplished when the ferry is at the shore where additional personnel may be available. In the manned mode, an additional crew man or engine man could be carried; this would improve the casualty risk potential at the expense of personnel exposure.

Logistically, the automated ferry with its greater complexity would necessitate a maintenance, repair and supply chain with more people, spare parts, and equipment than that of a simple non-automated ferry. Personnel exposure would not increase since such a logistic chain would be to the rear of the crossing operation.

Transport of the ferry units poses similar problems for both modes of ferry. Although unit trailers would be towed by the vehicles destined to become a ferry cargo, it is expected that situations will occur where the tactical situation is not fully resolved and where the combat vehicles will require mobility unhampered by trailers. For some periods of time or for some distances, the trailers would require movement by alternate prime movers. A choice may be required between augmenting the total vehicles of the armored organization for this contingency and between having the trailers towed at all times by designated non-combat vehicles. This also leads to the questions of whether the ferry properly should be organic to the armored organization or should be a separate ferry unit attached to the armored organization when required.

The salient points which emerge are:

The remote-controlled/automated ferry has some weight and personnel exposure advantages in situations of light enemy fire (14.5 mm and below).

In cases of organized opposition with potential use of heavier weapons, the remote-controlled/automated ferry has no advantage except in reduced personnel exposure.

Mission reliability and survivability are not expected to differ widely between the remote-controlled/automated and the armored-manned modes of ferry operation.

The remote controlled/automated ferry will have greater logistic demands. Transportation questions exist in either mode if the ferry is hauled by trailer, that is, questions concerning the adequacy of armored vehicles as tractors versus the need for separate or additional tow vehicles. Furthermore this bears upon the organizational position of the ferries.

7.5 SUMMARY OF FINDINGS

A major step increase in military worth is provided between the basic concept of an organic, self-powered, quickly deployable assault raft and conventional bridging or rafting equipment.

In addition of a remotely piloted feature to this basic concept provides a smaller relative increase in military worth over the manned version in terms of:

(a) operating capability at night or under conditions of poor visibility;
(b) reduction in weight (probably about 1.5 ST) because of less required armored; and
(c) reduction in personnel exposure because of the elimination of the on-board pilot.

8. SCALE-MODEL TESTING

Section 5.7 noted that the principal risk areas for RPAR concept are concerned with operational rather than hardware factors. In particular, the ability and level of . ·aining required for the remote pilot to control the path of the raft and to perform the docking maneuver is not established. The accuracy of control and response to environmental conditions under instrument control cannot be predicted without testing.

The factors suggest that the logical next step for evaluating RPAR feasibility is an experimental investigation of remote human control using a full-scale or partial scale test bed. A small-scale test model would have considerable cost advantages. However, if the scale is too small, the hydrodynamic behavior of the craft will not properly simulate that of the full-scale raft, and the response to control inputs will not be realistic. For these reasons, a final test bed should not be less than one-half scale. Full-scale would, of course, be preferable and should be used if possible within the constraints imposed by available funds and the size of the body of water available for testing.

Extremely small-scale models must be based on hydrodynamic scaling laws to properly predict hydrodynamic drag. Thus, they are not typically geometric scale models and would have limited use in investigating operational parameters. Their use should be properly limited to testing during the design phase in a towing tank prior to sizing the required thrust.

A full-scale test bed will have a cost in the range of the prototype unit of Table 9. Assuming that it may be necessary to reduce this cost for the test-bed or that other size constraints may apply, the following paragraphs discuss the one-half scale approach. (See Table 18.)

TABLE 18. HALF-SCALE TEST MODEL CHARACTERISTICS

	Full Scale	1/2 Scale
Hull Depth	4 ft	2 ft
Hull Beam (Total)	20	10
Hull Length	36	18
Draft (Light-Full Load)	1-3	1/2-1 1/2
DWT	35 ST	4.375 ST
Ramp (Length x Width)	10 x 14 ft	5 x 7 ft
Max. Speed	3.5 m/s	2.48 m/s
SHP (Estimated)	350	52
Engine Speed (L x W)	16 x 10 ft	8 x 5 ft

The principal difficulty arises in connection with the power plant vis-a-vis the hull depth of 2 ft.

Two small air-cooled gasoline engines, such as VW engines, might be installed together with internal pumps. A 360° rotating nozzle at the pontoon bottom level would have to be designed for this purpose. This would not be a simple task, even though efficiency, for this model, would be of secondary importance. This approach would, of course, provide the additional opportunity to design and test a prototype thruster which ultimately could serve as an alternative to the use of the proprietary Schottel unit.

Alternatively, two outboard motors, modified to fit on a fully rotatable carriage which also can be lowered and elevated, may be feasible, In operation, the propellers would protrude below the bottom; in retracted position the engine would protrude above deck level. If engines with an overall height of 3 to 3 1/2 ft could be found, such a scheme would be feasible. The propellers could be fitted with shrouds to improve performance in this application. The diameter of the well in the hull would preferably be about 2 1/2 ft but larger diameters could be accommodated.

The requirements for a drive to give directional control would be analogous for either system. Likewise, the data processing system to produce the correct engine throttle settings and propuslor direction in response to the pilot commands would be similar.

We expect that the developments of this latter system, both in hardware and in software, will be analogous to that of the full-scale ferry. Although only two propulsors would be present on the model half ferry, the basic elements of the full-scale system are required, and the development process would be similar. The control consoles would be prototypes of the full-scale item.

For demonstration purposes the radar surveillance system could be omitted. The telemeter link would be required, however, and voice communication can be provided by simple portable (hand-held) VHF or UHF transceivers.

To recapitulate, the largest (or most costly) mechanical item would lie in fitting a propulsion system into the shallow hull. Although the propulsion system can be different from a pump-jet of the Schottel type, it must have similar performance characteristics. The other major cost and time element would be the control system. Some simplifications are feasible from a full-scale version but the development work which would be required is similar.

A variety of other options exist. Hull materials can differ from full-scale construction, e.g., it may be more convenient to turn to reinforced plastics than to use steel or aluminum. A single ramp may suffice rather than ramps at both ends. The ferry can be one piece rather than collapsible.

The half-scale model would suffice to demonstrate the capabilities of the ferry and could carry a demonstration load such as a jeep without difficulty. It would be an appropriate size for trials in the MERADCOM boat basin and for potential construction/modification in base facilities.

Appendix A

HULL SECTION HINGES

Appendix A

HULL SECTION HINGES

The position and the requirements for the hinges are determined by the scheme of sectioning and stowing the ferry hull. This, in turn, is constrained principally by the transportability conditions of the ferry on its carrier (trailer or truck). The significant results are that there must be a center section with two wing sections which fold up and over to rest on top of the center section. The wing sections must rotate about their own centroid either 180° or 0°; their position relative to the center section changes 90°; in the deployed condition the hinge line will lie at deck level; any hinge powering mechanism must keep the ends of the sections clear; and, the treads of the large tracked vehicles will cover the hinge line and the juncture of wing and center sections.

Under field conditions, the tracks of combat vehicles pick up considerable amounts of mud and gravel which later is thrown off. The ferry deck will accumulate such deposits and the vehicle tracks passing over such debris damage the deck roadway surface. Therefore, it is necessary that the entire hinge lie below the roadway surface and, moreover, that the hinge be designed to avoid accumulation of debris that might disable its action.

Considerable emphasis must be placed on simplicity of the device, both for operation and for maintenance and repair. For example, a number of schemes can be devised in which the wing sections ride on an arm hinged and driven at the center section. However, in order to make such schemes work, the rotation of the wing section must be intermittent, or a fulcrum must be shifted in the course of the action. For field launch and deployment of the ferry, the extension and stowage operation should consist of a single uninterrupted action with a minimum of operation by attending personnel and with a minimum of mechanical control mechanisms.

If the wing section is stowed upright, it can be moved to its deployed position by a bell-crank arrangement with about a 180° motion of the crank, as indicated in Figure A-1. A second arm is required to complete the parallelogram and to maintain the wing section in its upright position. Since the main crank moves 180°, the control arm must lie in a different plane from the main crank which bears the weight. The arms must be buried within the 16-ft long hingeable length of the sections and would require deep slots or cuts in the structure of the sections. Therefore, this arrangement is not considered further.

If the wing sections are stowed upside-down, a compound hinge can be developed which contains an intermediate link between two hinge pins. As shown in Figure A-2, this type of hinge relates a 90° movement of the link to a simultaneous 90° rotation of the wing section. This relation is maintained by a toothed mating surface or be crossed cable straps. The wing section "rolls" on the similar rounded edge of the center section. Unfortunately these rounded edges leave a gap in the roadway which would hamper wheeled vehicle movement and which would collect debris to the possible extent of making operation difficult. Therefore this type of hinge likewise has serious drawbacks.

The Soss-type hinges, as shown in Figure A-3, previously have been considered for use in the Wet Bridge development. This hinge has the advantage of permitting the deck edges of adjacent pontoon section to remain closed thereby maintaining a continuous surface which prevents the intrusion of debris into the mechanism. The sliding pin arrangement, however, must be analyzed further with regard to its shear and torsion load-bearing capabilities, considering the heavy stresses placed upon this hinge during ferry operation.

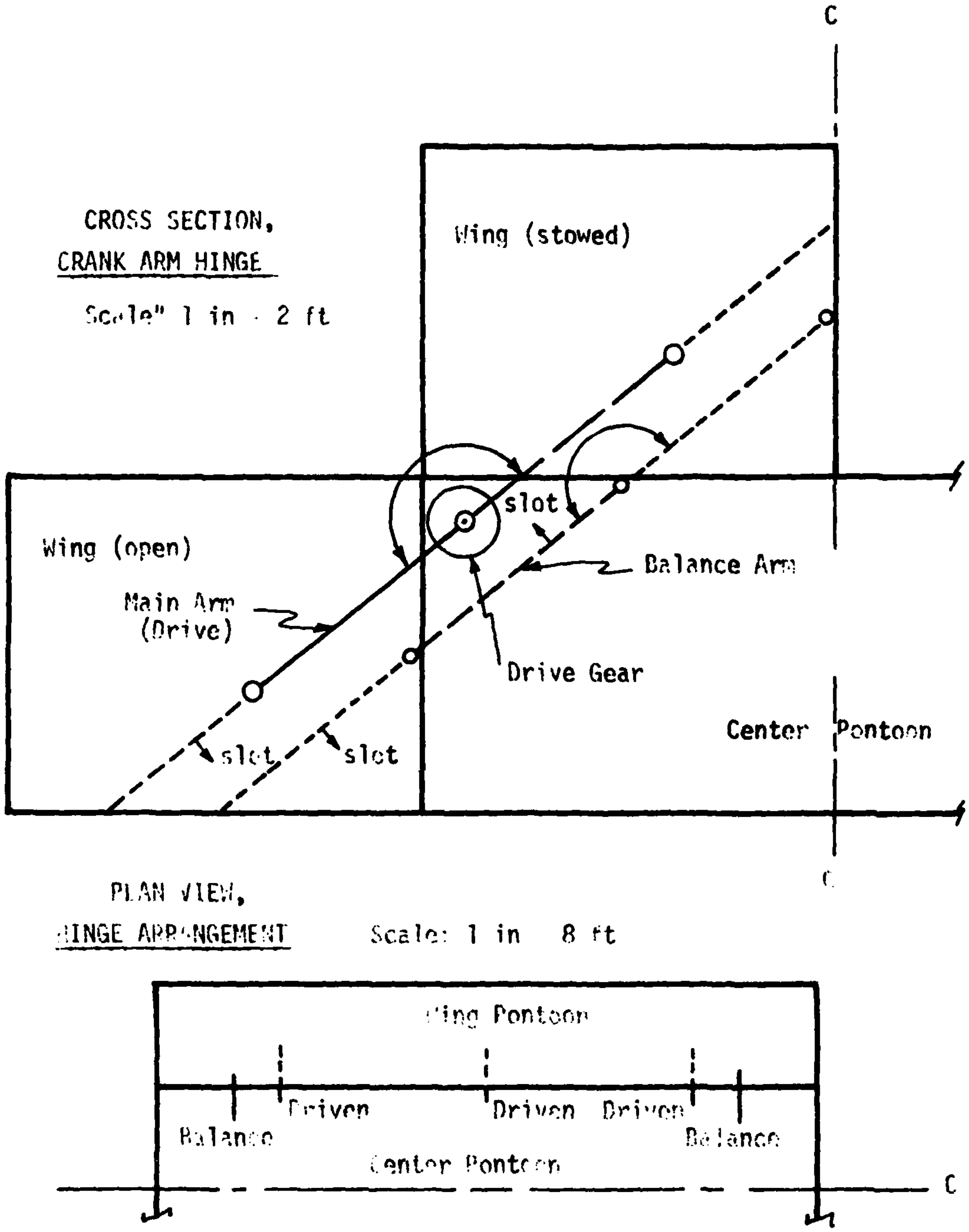


FIGURE A-1 CRANK ARM HINGE

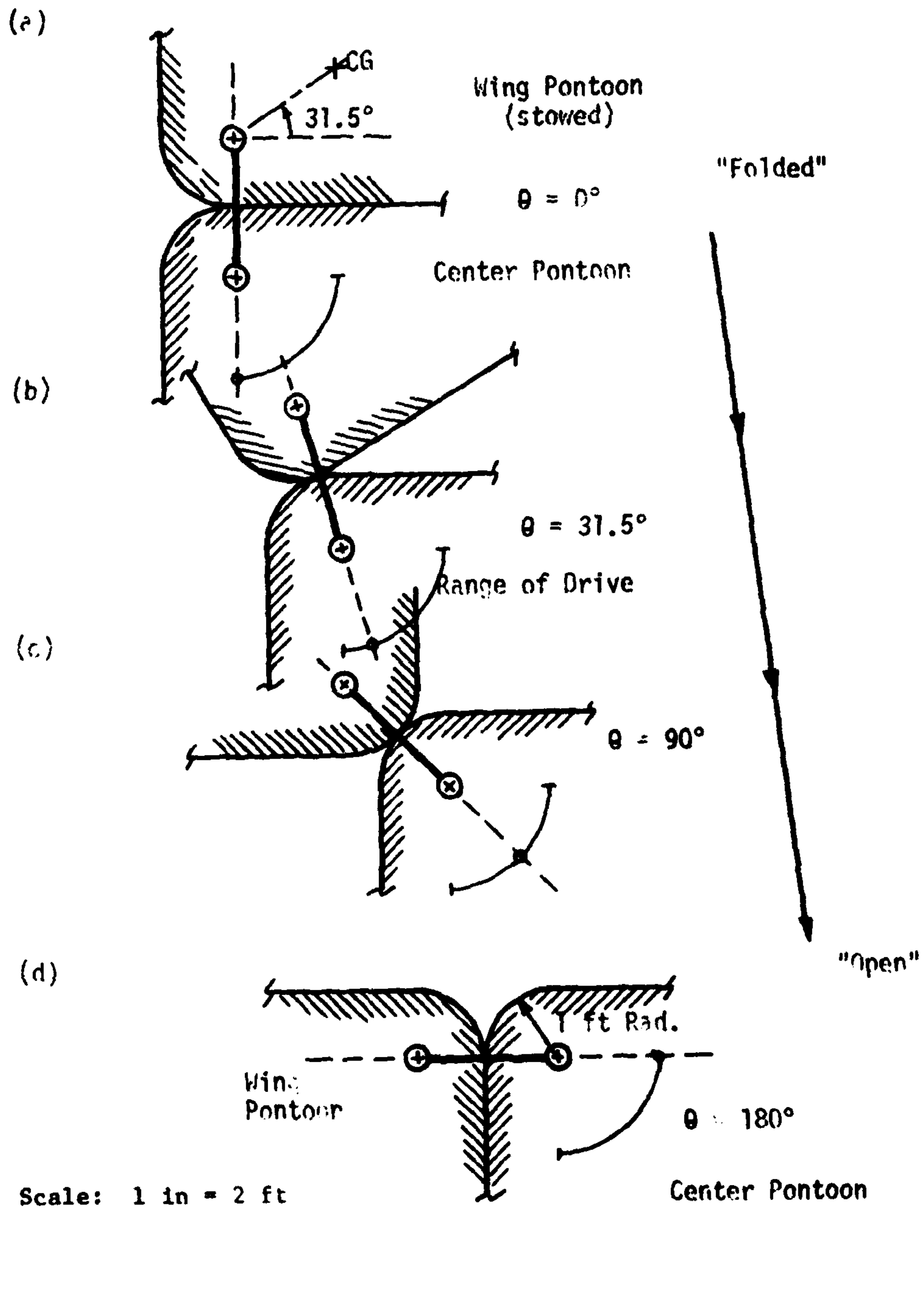


FIGURE A-2 LINKED "ROLLING" HINGE

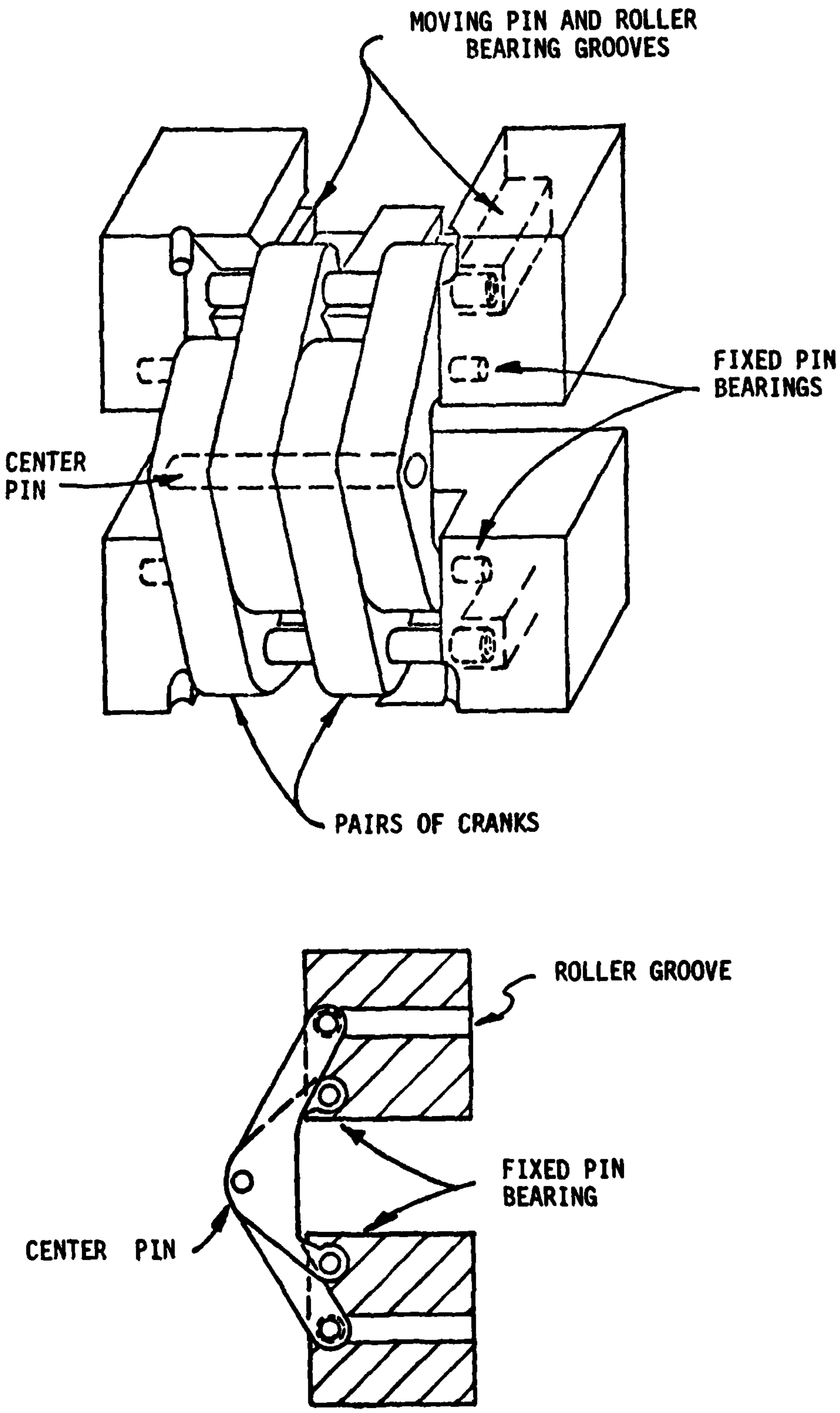


FIGURE A-3 PRINCIPLE OF THE SOSS HINGE

A hinge can also be effected by a simple hinge pin at the deck edge level, with the hinge protected by gratings which mesh in the stowed position. This arrangement is sketched in Figure A-4. While the arrangement is the most simple, its main drawback lies in the possibility of debris lodging between the ribs of the grating, or damage and distortion to these ribs, which would prevent closure. The ribs can form the transverse members of the deck grillage structure and would add limited weight while the hinge could be continuous for the 16-ft length of level deck.

It is expected that in any of the types of hinges noted here, the powering or driving forces would be applied separately from the hinge mechanism itself. This power-operating mechanism is discussed in Section 4.2.3 and would apply to all hinge types.

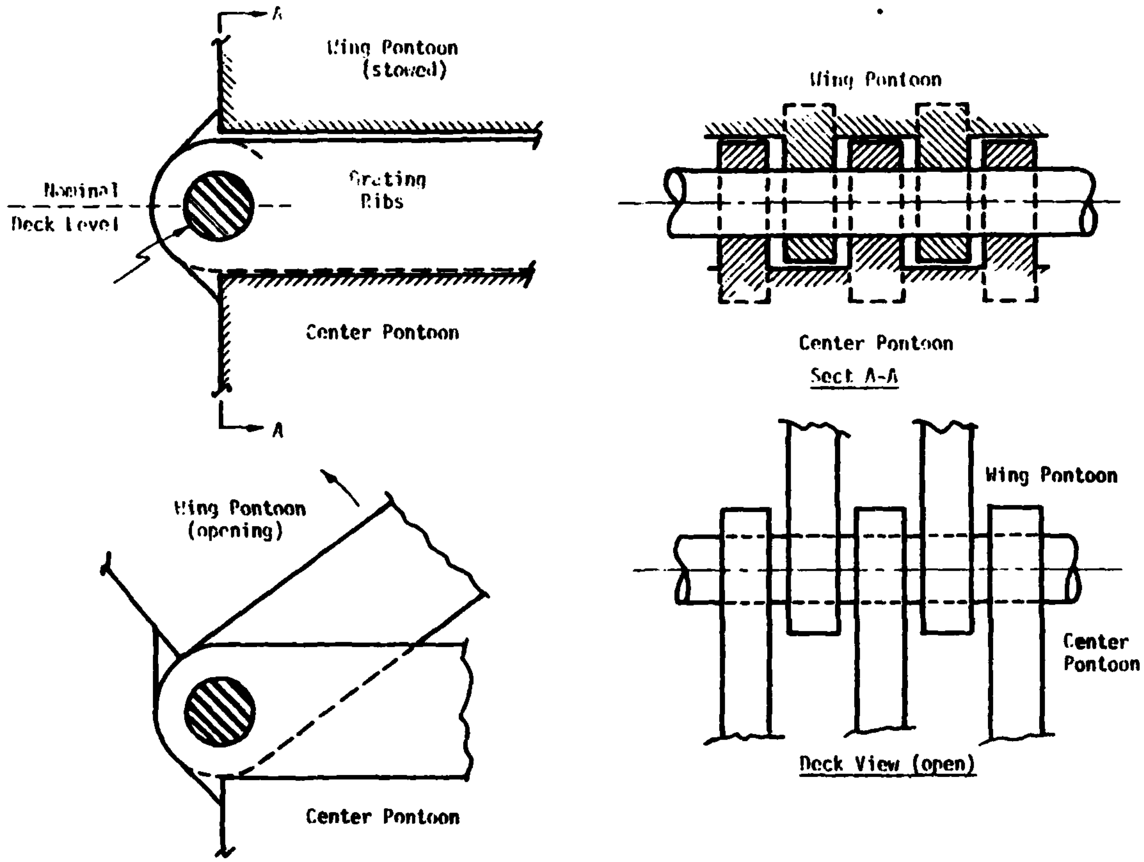


FIGURE A-4. HINGE WITH PROTECTIVE GRATING

Appendix B

FERRY UNIT LAUNCH CAPABILITIES AND PROBLEMS

Appendix B

FERRY UNIT LAUNCH CAPABILITIES AND PROBLEMS

B.1 SHORE TYPES

Three general types of shore profile would each present separate launching problems. These types are shown in Figure B-1. Figure B-1(A) represents a continuous gradient of the shore line. Figure B-1(B) probably is more common in that there is a break in the gradient somewhere above the immediate beach area. Figure B-1(C) indicates the most difficult situation, where the shore drops off to the water by a high angle. It is noted that this type of shore is addressed by the stated requirement that the ferry ramp accommodate a minimum rise of 1.5 m (4.92 ft), above water level. On the other hand, the minimum gradient to be considered in situations such as Figure B-1(A) is a 7:1 gradient or a slope of about 8.1 degrees.

B.2 ASSUMPTIONS

The hull section to be launched is taken as 36 ft long x 20 ft wide x 4 ft deep with a weight of 12 ST. It is unfolded prior to launch. The carrier is a double-axle, double-wheeled trailer with a 10 ft x 10 ft bed. The bottom of the load is 3.5 ft above ground level, as shown in the cross-section shown in Figure B-2.

Since the only way to get the section off the trailer (other than by lift) is to slide it off, two skids moving with the section are fitted under the section on rollers. As the section moves back, the skids and load will pivot when the center of gravity of the load passes the rear point of trailer bed. It is assumed that the trailer bed is fixed and does not deflect. For this example, we assume the skids were 30 ft long, whereas the hull section is 36 ft long. As shown in Figure B-2, the load begins to pivot when it has moved 5 ft back. We also assume that the skids can move back a total of 15 ft, at which point their angle with level ground would be about 6 degrees.

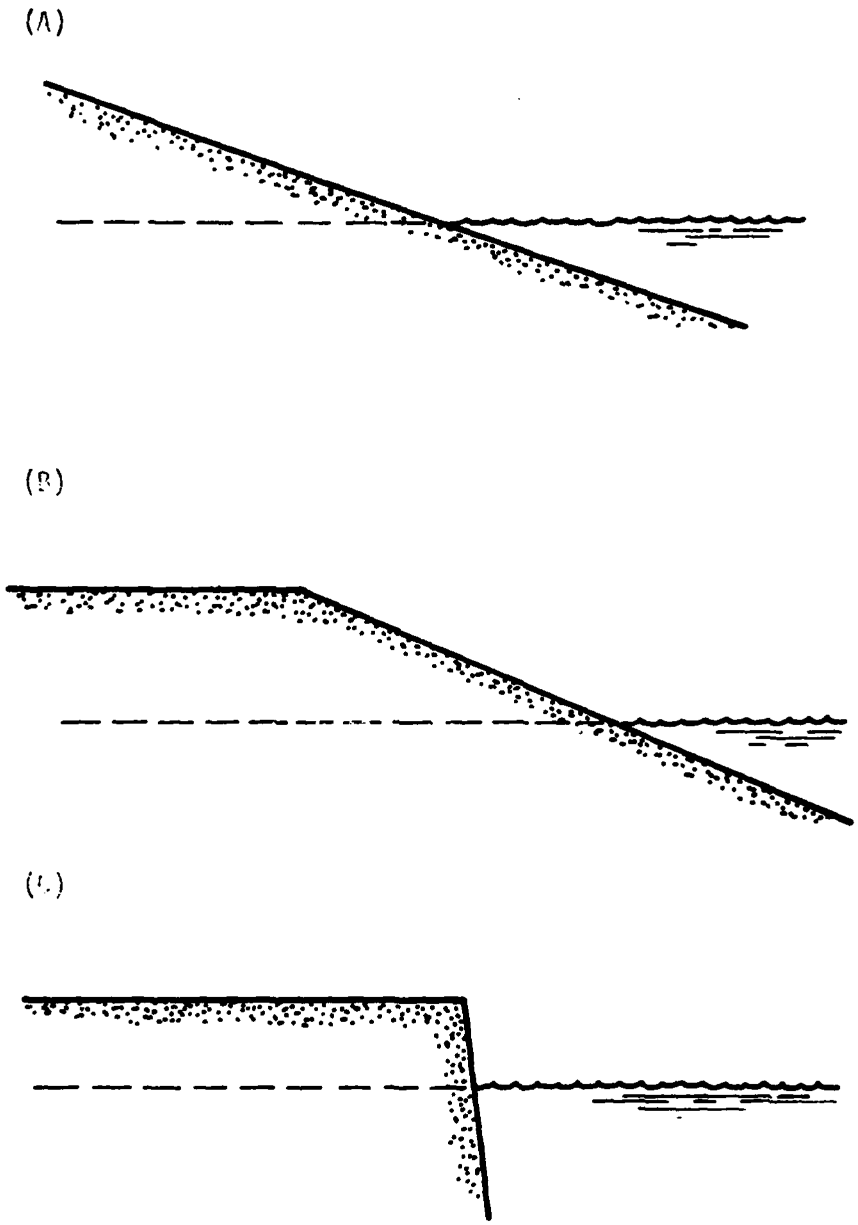


FIGURE B-1 TYPICAL SHORE PROFILES

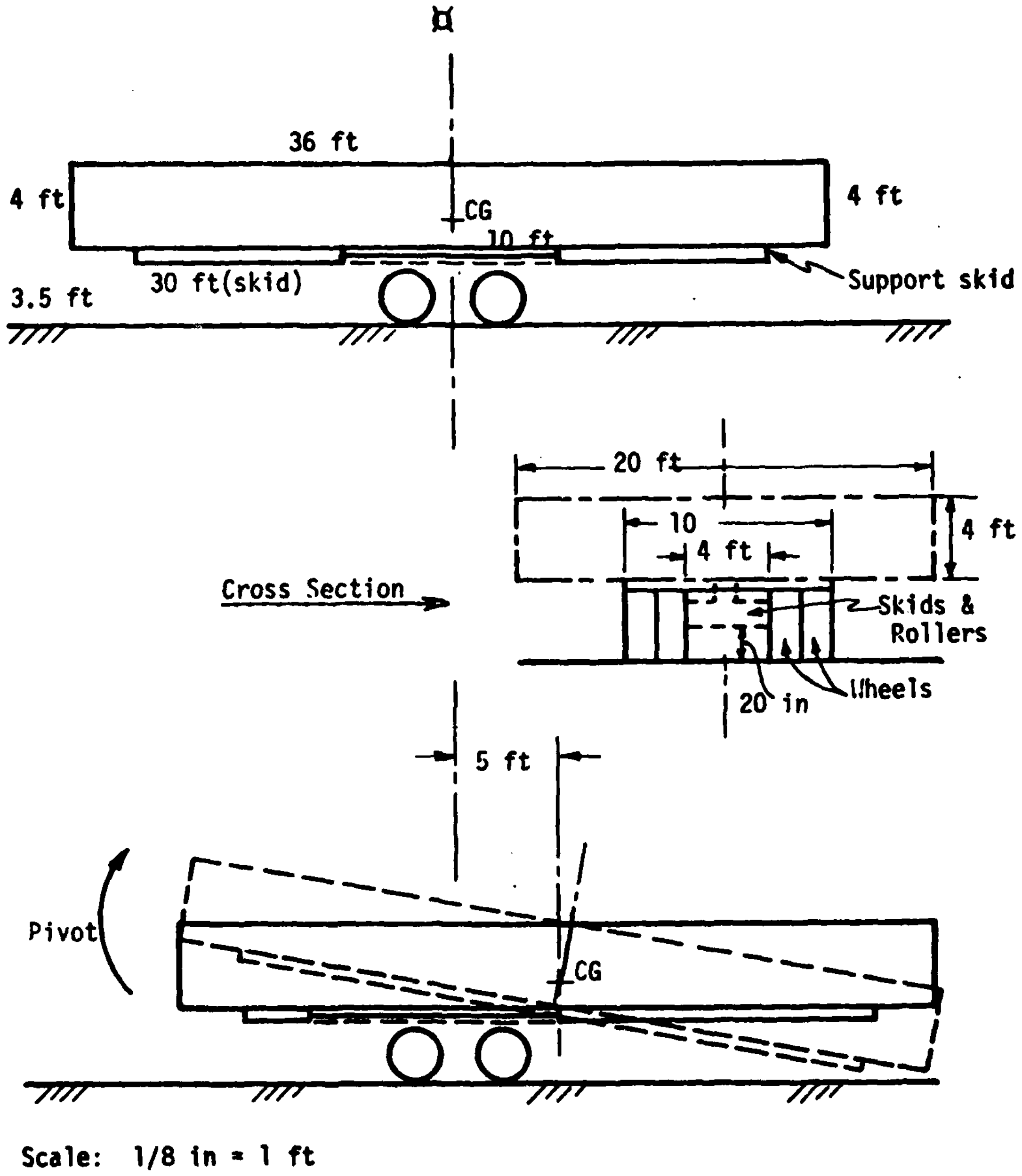


FIGURE B-2 LAUNCH FROM TRAILER

B.3 DISCUSSION

First it is necessary to determine the behavior of the hull section sitting on its skids or cradle. As a craft moves down an included plane, the buoyancy increases with increased immersion. At some point, the moment exerted by this buoyancy will cause the hull to rotate, even while the buoyancy is insufficient to fully support the craft. As the craft moves further down the incline, it gains further buoyancy until it floats off on an even keel.

In this instance, the supporting skids can rotate at any time after the center of gravity of the load has passed the end of the trailer bed. The travel of the skids, however, is limited to 15 ft. A second limitation is that the deck of the section remain dry, i.e., that the maximum draft forward must not exceed 4 ft.

For a preliminary examination such as this, only the <u>static</u> conditions are considered. These, however simplified, point out the limitations on the launching process. Static conditions simulate a slow and restrained launching process, whereas for a free launch where high hull section velocities may be expected, the behavior would differ somewhat. Figure B-3 provides the definitions of the values and terminology used in formulating the problem.

Basically, three variables enter the problem; the angle of inclination, α; draft forward, d; and the distance of the pivot point from midships, a; the expression for the buoyancy (B) can be reduced to:

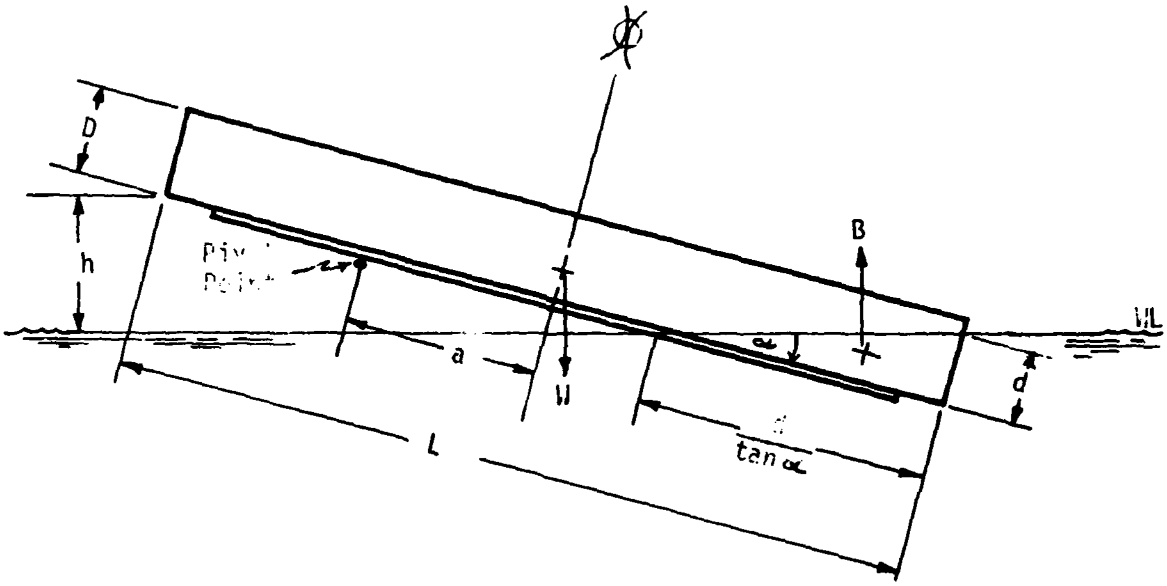
$$B = \frac{d^2}{\tan\alpha} (0.2964) \text{ in short tons}$$

The expression for Moment about the Pivot Point becomes

$$W\, a \cos\alpha = B\left(a + 18 - \frac{d}{3\tan\alpha}\right)\cos\alpha$$

Dimensions:

L	=	36 ft
D	=	4 ft
BM	=	20 ft
W	=	12 ST
B	=	Buoyant Force, ST



Scale: 1 in = 8 ft

FIGURE B-3 PONTOON LAUNCH: NOTATION

The results of combining these two expressions, and solving them by substituting a series of values for two of the three variables, are summarized in Figure B-4. The values derived from this general solution can then be related to the physical geometry of the assumed trailer and the various shore profiles. It is noted that the angle, α, is composed of two parts. One is the angle made by the skids to the level ground, due to the elevation of the pivot point at the rear end of the trailer bed. The other is the slope of the shore. The angle α referenced to the horizontal water surface plane.

Rotation of the hull can take place in two distinct actions. First, as the skids are moved aft, the hull will tend to tilt away. At a given launch inclination, the hull must acquire a specific bow draft before it pivots back upward. This is the situation depicted in Figure B-4. Second, there also will be a point at which the hull tends to rotate upward about its keel at the stern. This is a similar formulation, with the value for "a" taken at the maximum of 18 ft. The relationships which result are shown in Figure B-5.

From the two Figures, it will be seen that the latter event always takes place after the first rotation about the pivot point on the trailer. Figure B-5 also shows the length of immersed bottom when the latter event takes place. In addition, a curve is shown on Figure B-5 which shows the combinations of α and "d" required for full flotation of the hull; in all cases this requires a greater immersion than necessary for rotation. This means that some weight of the hull will be resting on the launch arrangement when the hull rotates from the skids, and that the hull has to be moved further into the stream after the rotation.

On a constant slope shore, as shown in Figure B-1(A), when the hull is first moved relative to the trailer, the geometry will be as indicated in Figure B-6. Assume that "a" is 5 ft and that the waterline is at deck edge, i.e., that "d" = 4 ft. At values of α less than 60°, the moment caused by the buoyancy of the immersed bow is greater than that of the weight of the hull, and the hull will pivot. At an α which is

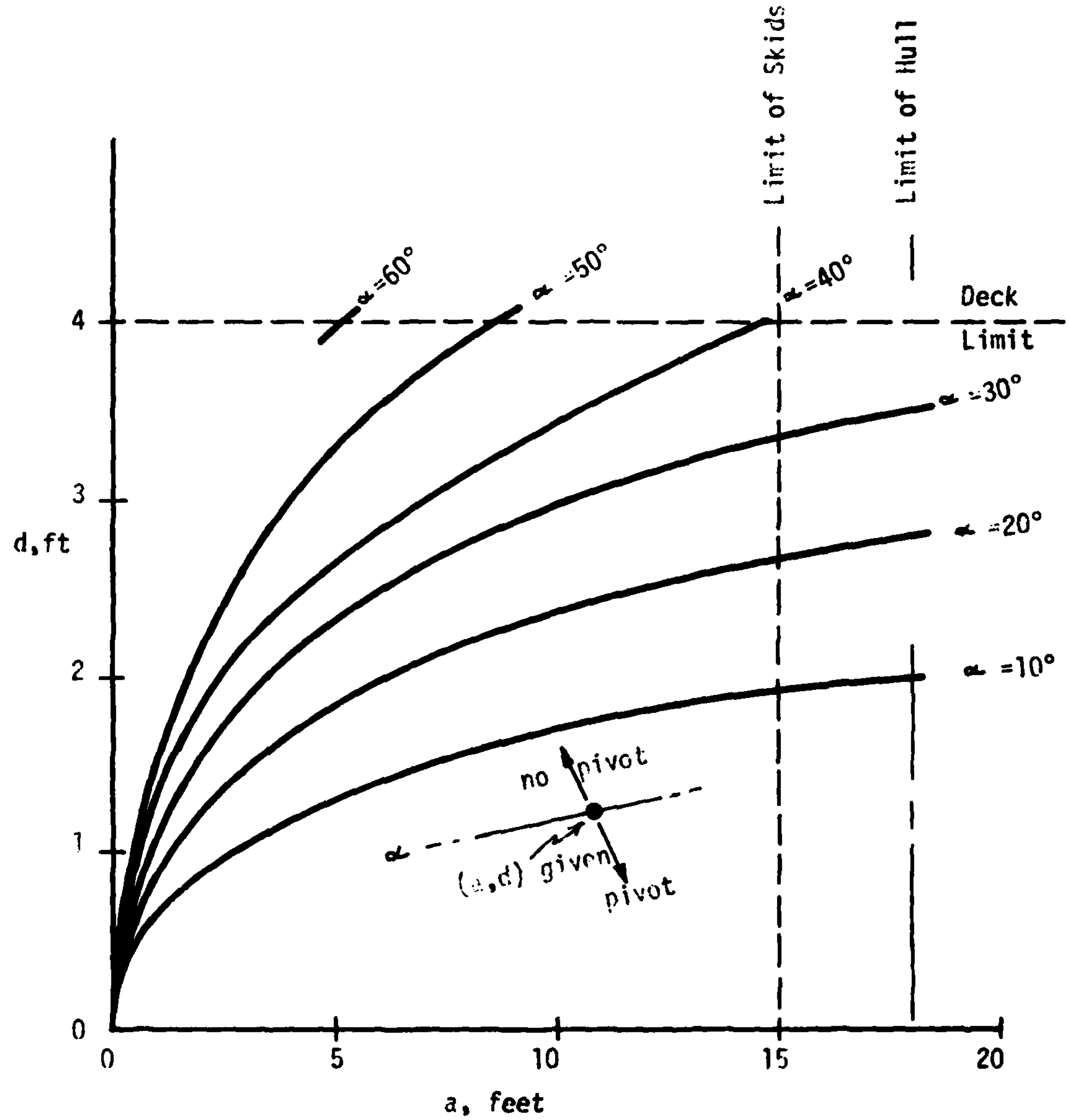


FIGURE B-4 RELATIONSHIP OF LAUNCH ANGLE, PIVOT POINT AND BOW DRAFT

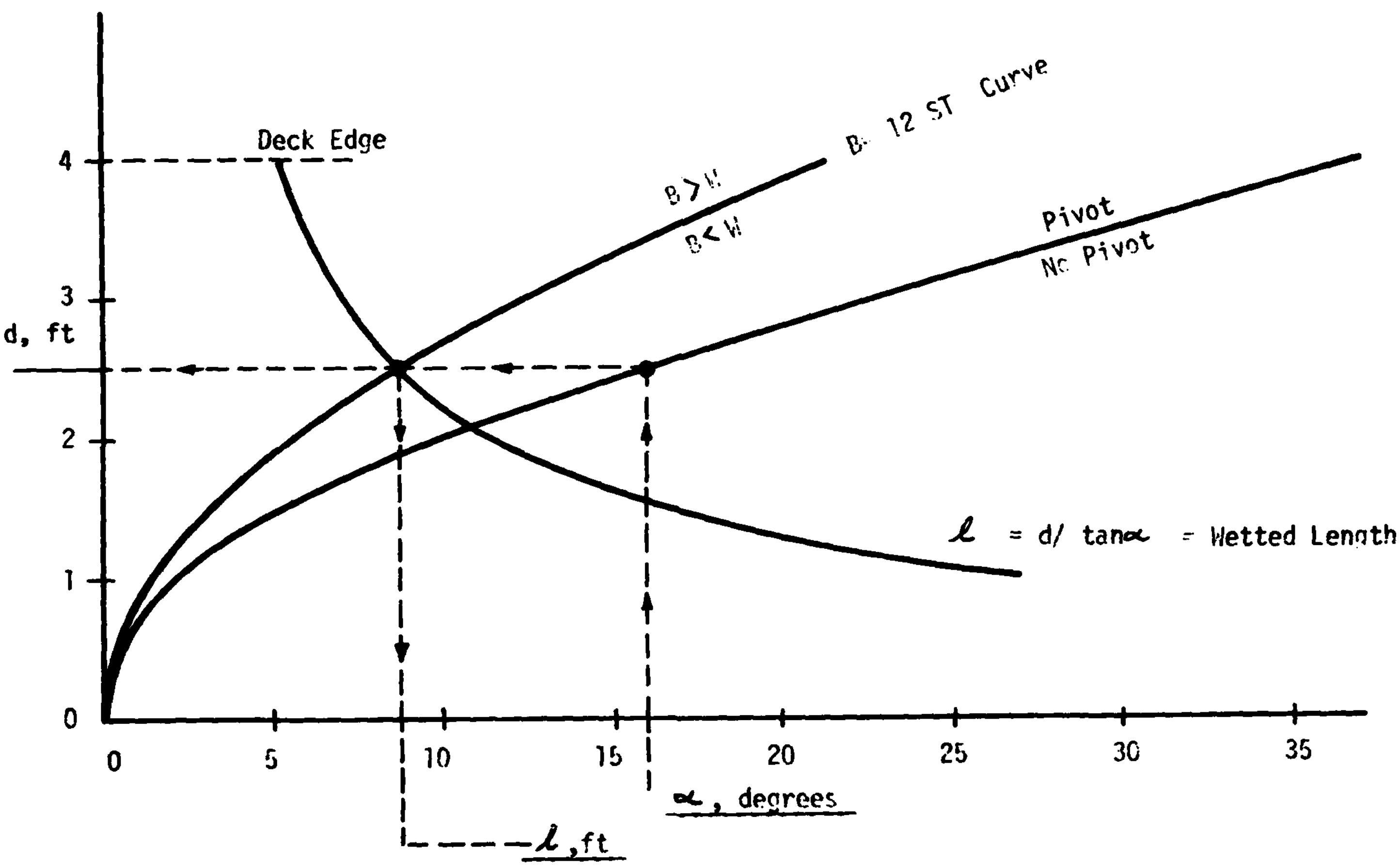


FIGURE B-5 RELATIONSHIP OF BOW DRAFT, INCLINATION, AND WETTED BOTTOM LENGTH, FOR ROTATION ABOUT KEEL AT STERN OF FERRY

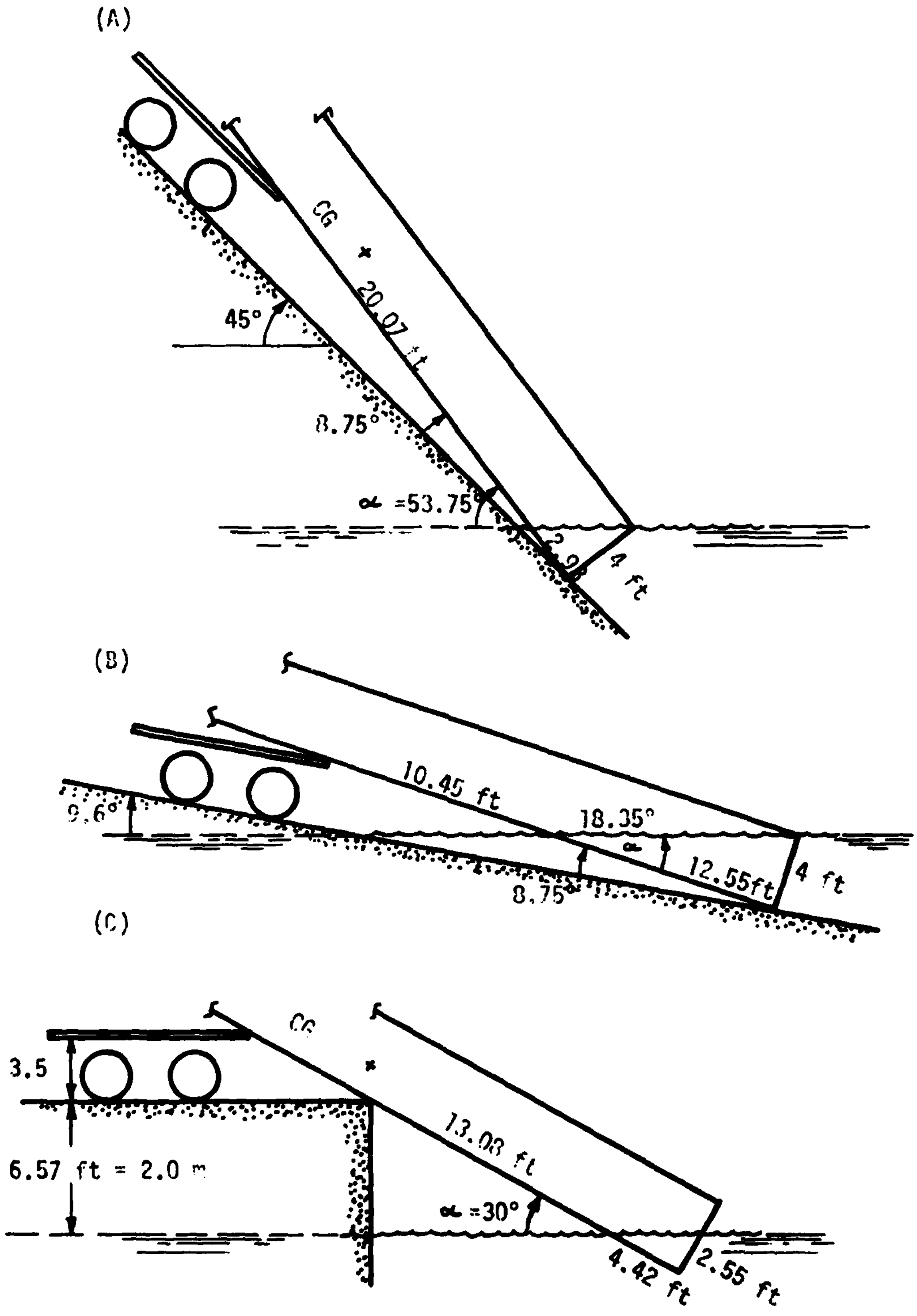


FIGURE B-6 INITIAL LAUNCH CONDITIONS

greater than 60°, the hull will not pivot about the support point at the end of the trailer bed.

In this example, the pivot point is 23 ft from the end of the hull at a height of 3.5 ft above the ground and subtends an angle of 8.75°. The bottom slope therefore must be <u>less</u> than (60 - 8.75°) or about 51°. Figure B-6(A) shows this situation for a shore and bottom slope of 45°. In this illustration, the bottom pressure of the hull would have passed zero and the hull would lift slightly. When the hull comes free, "α" and "d" become related by the expression

$$S \sin \alpha = \text{constant} = L \sin\alpha \ d \cos\alpha$$

where L is total length from pivot point (a+18) and S is distance of the pivot point to the water's edge. In Figure B-6(A), L = 23 ft, S = 20.07 ft. The constant is determined from initial conditions. The computed values of the equation are superimposed on the curves of Figure B-4 and Figure B-7. An α of about 53° results; the hull lifts, but barely. In Figure B-6(B), the trailer is at water's edge, α = 18.35° and beach gradient is 9.6°. A similar solution gives an α of about 12° at a "d" of 2.7 ft for the pivoted hull. This case also is shown in Figure B-7.

The semi-graphical solution approximates the values; substitution of the above relationship into the moment equation would give precise values.

Figure B-5 indicates that in the steep shore case, or in the second case, the hull would <u>not</u> pivot on its heel. It would require a further mechanical effort in an offshore direction in order to be floated off. These values indicate that such a launch is feasible from a steep shore to gradients of approximately 10°. If the trailer is submersible, the angular range is extended. Because of the trailer height of 3.5 ft (assumed) shallow water launch at low shore gradients would require other approaches such as dynamic methods or lift-off.

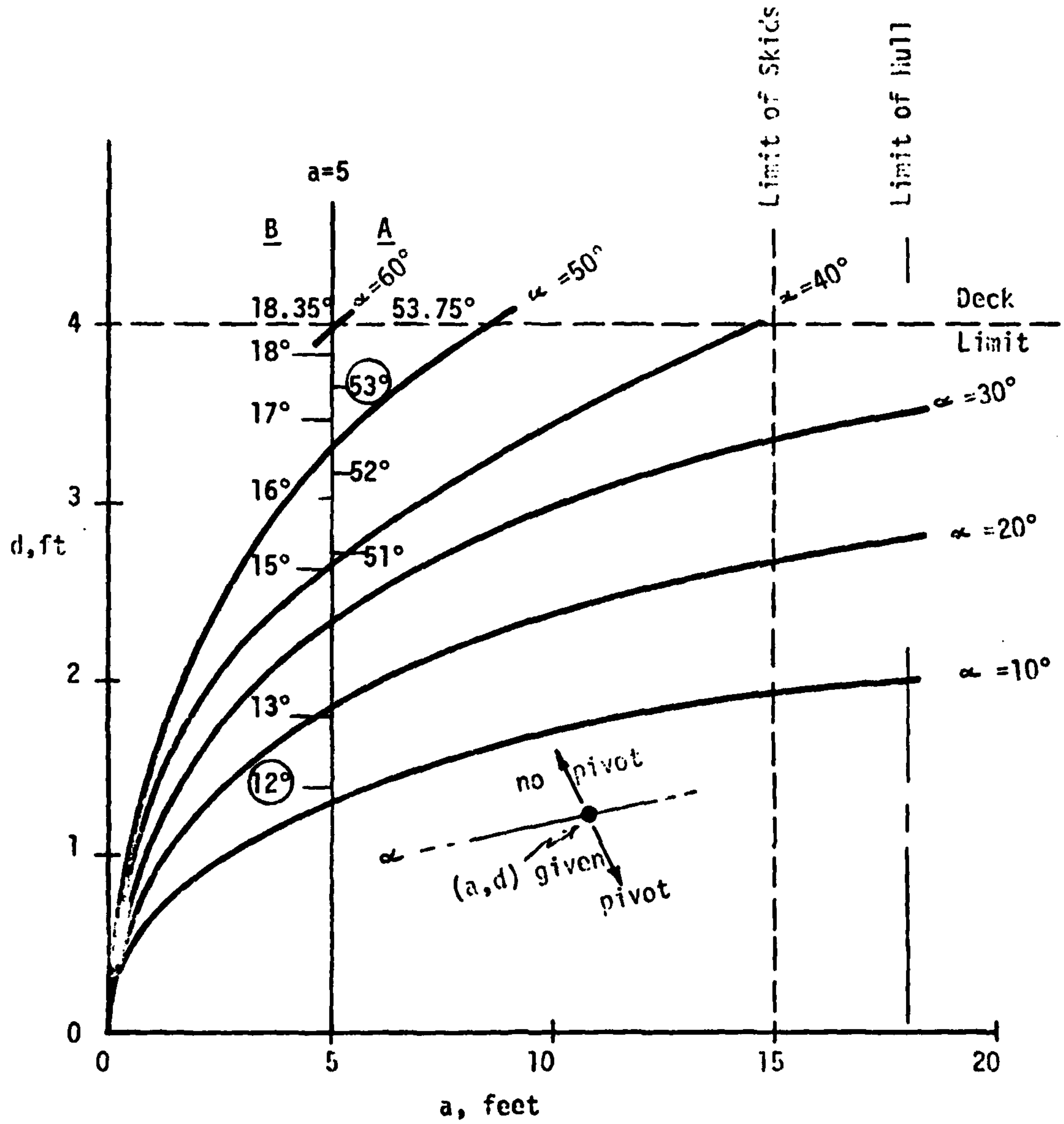


FIGURE B-7 RELATIONSHIP OF LAUNCH ANGLE, PIVOT POINT AND BOW DRAFT

The first two shore configurations shown in Figure B-1 essentially become the same launch problem. In Figure B-1(B) the trailer must be backed past the break in the shore profile; then the launch considerations become identical to those of Figure B-1(A).

For the third configuration, Figure B-1(C) the skids and hull must be permitted to rotate past the usual baseline. Figure V-6(C) illustrates such a situation with a 2 meter high embankment. The geometry dictates that:

$$\frac{(h + 3.5) + d \cos\alpha}{(a + 18)} = \sin\alpha$$

Solution of this relationship is superimposed upon the Moment Equation of Figure B-4 in the Figure B-8. The combined solution indicates feasible launch conditions. For example, the $\alpha = 25°$ curves cross at about a = 12 and d = 2.85 ft. The $\alpha = 30°$ curves cross at a = 6.5 ft and d = 2.55 ft. Provided the arrangement can be supported at these angles, such launches appear feasible.

CONCLUSION

The launch concept can accommodate the various shoreline profiles for static launching under a dry hull deck edge condition. A sliding release mechanism between the cradle-skids and the hull bottom is required. Dynamic launch behavior must be examined when hull and carrier parameters are more closely defined.

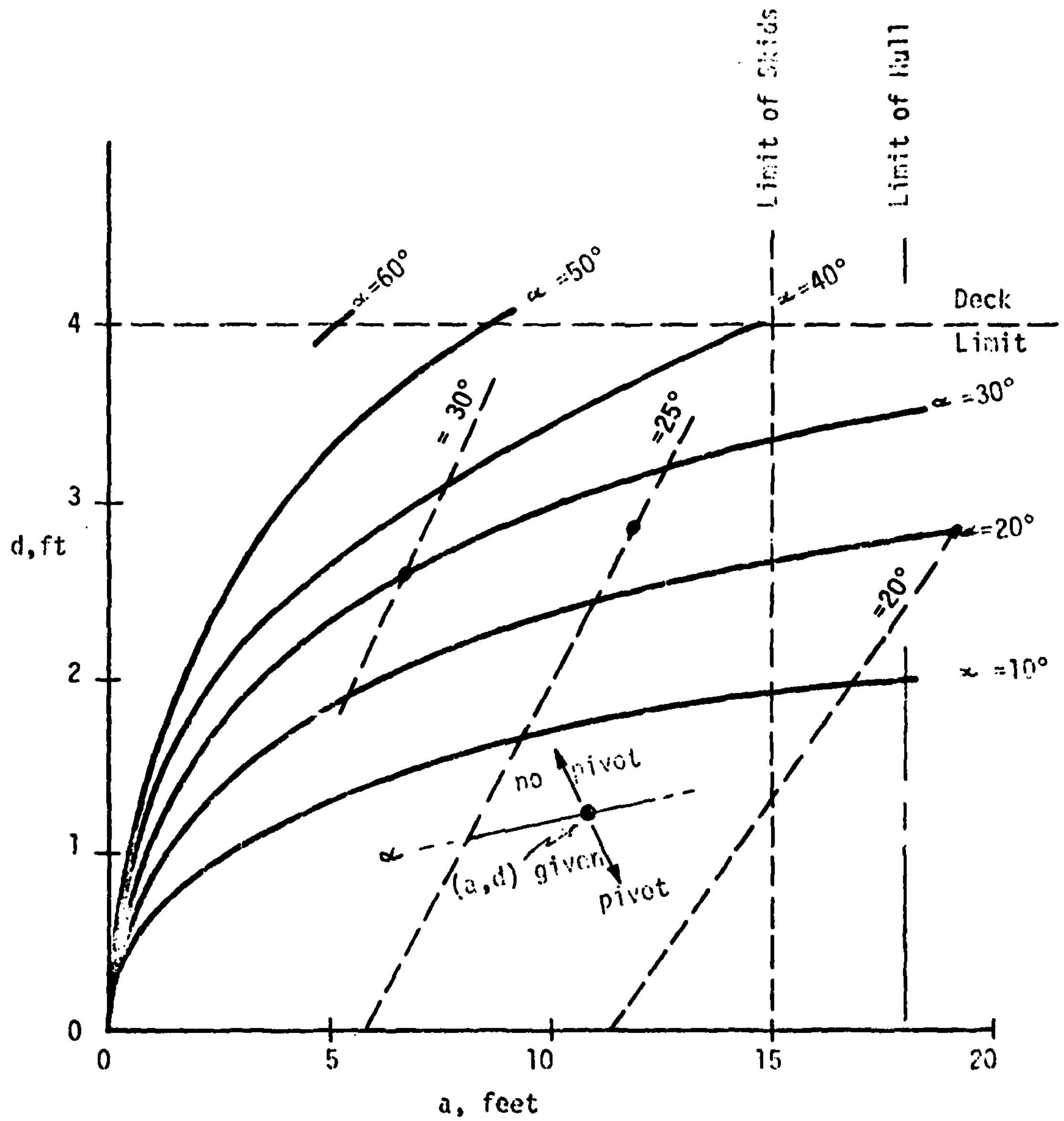


FIGURE B-8 RELATIONSHIP OF LAUNCH ANGLE, PIVOT POINT AND BOW DRAFT

Appendix C

AUTOMATIC NAVIGATION SYSTEMS

Appendix C

AUTOMATIC NAVIGATION SYSTEMS

C.1 HOMING

A sensor on the ferry measures the angle between ferry heading and target; this feedback is used to correct the ferry control system to a course toward the target.

At a low differential speed between ferry and target--in this case, at a low speed differential between ferry speed and current velocity--or at a negative differential, an undesirable tail chase results. Figure C-1 indicates the ferry trajectory in the case of a low differential speed.

Since there is a time lag between the angle value given by the sensor, and an actual physical change of course, more sophisticated features probably would be required to ensure stability of the system. The rate of deflection, as measured by the sensor, would be one of the parameters that would be useful in this respect.

In the event the ferry encounters large variations in current speed or direction, the system must have sufficient range and stability for adjustment to the varying conditions. As noted in Figure C-1, the values of three angles are relevant to the control problem:

α is the average heading of the ferry in relation to its base course. $\alpha = \sin^{-1} (V_c/V_f) \cos\beta$, where V_c is current velocity; V_f is ferry speed; and,

β is the angle between the intended course and the normal to the current or other reference.

δ is used here to designate the measured deflection angle as seem from the ferry by the sensor.

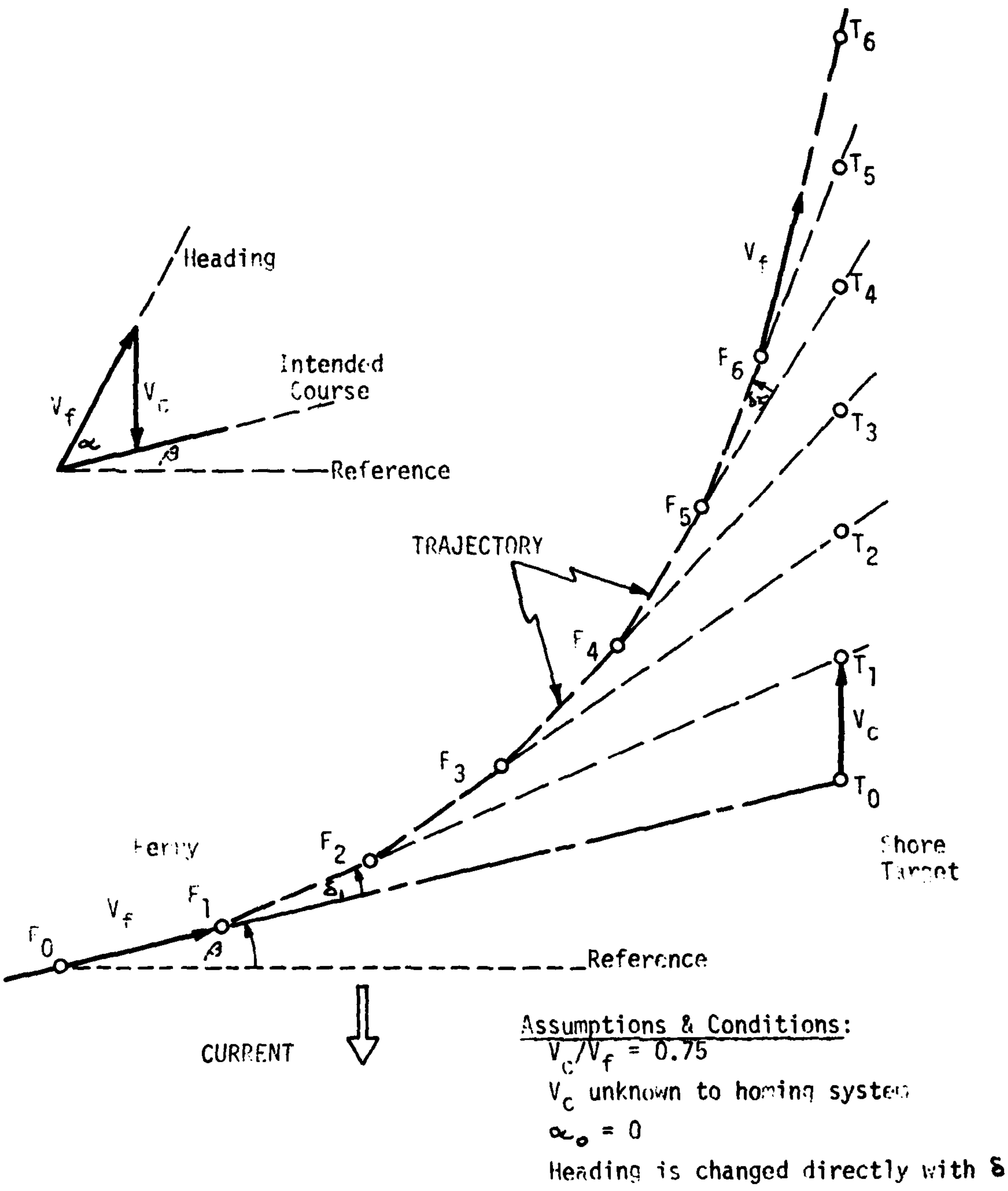


FIGURE C-1 RELATIVE MOTION OF FERRY AND HOMING POINT (TARGET)

The systems would require a wide range both in its computational capabilities and in the angular range of the sensor in order to handle all possible situations.

Figure C-2 indicates a trajectory when an initial heading angle is set into the control system. The feedback function also is changed as indicated. A stepwise simulation as represented by the sketch cannot fully reproduce the exact trajectory of the ferry. However according to this simulation the algorithm produced a reasonable trajectory and the miss distance between the point T_7 and the path between F_6 and F_7 is small. This type of control system therefore appears feasible.

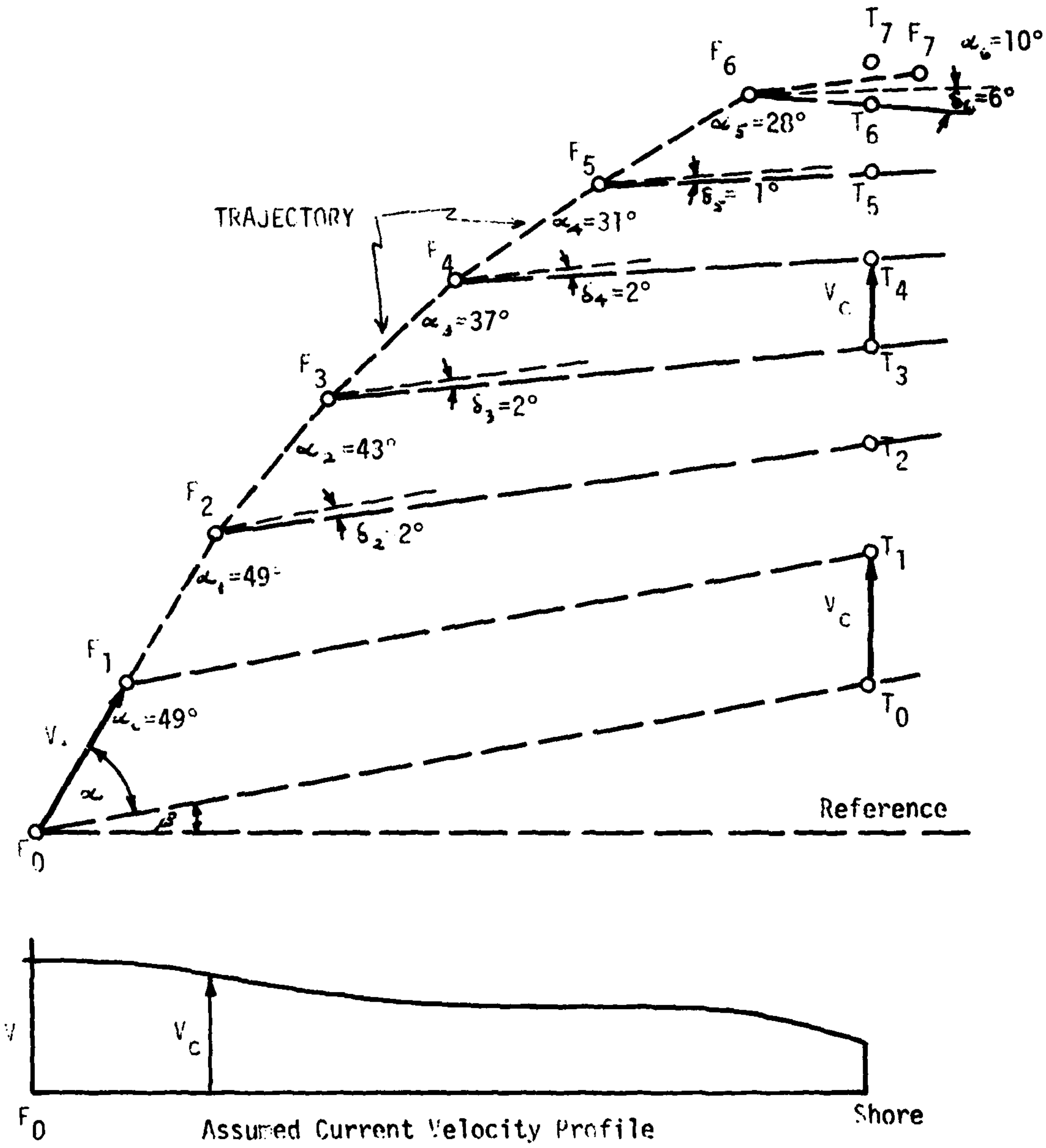
C.2 BEAM RIDING

The basic difference between "homing" and "beam riding" is that in homing a point target is ahead of the vehicle, while in beam riding some form of beacon is behind the vehicle. In the homing case, it is desirable to ride in to the target on a constant heading; in the beam riding case, it is desirable to ride out on a constant heading.

A homing target usually is an omni-directional signal whereas a beam may define only a radial line. The modes merge in their use when an omni-directional signal carries directional information. The VOR aircraft range is the prime example of this universal application.

Figure C-3 provides the basic relationships for beam riding and these are found to be similar to those for a homing system. It is possible to relate the offset ε from the beam (translation) and the angular error δ to the parameters of velocity and course V_c, V_f and β.

The main problems seem to arise from the physical type of beam that is used for guidance and its physical characteristics. For example, a laser approximates a single one-dimensional line whereas a RF beam may be a lobe modulated across its width. In some instances it may be advantageous to



Assumptions: V_f = constant
Navig. Algorith: $\alpha_{n-1} - 3\delta_n = \alpha_n$
α_c is given.

FIGURE C-2 RELATIVE FERRY MOTION WITH VARIABLE CURRENT

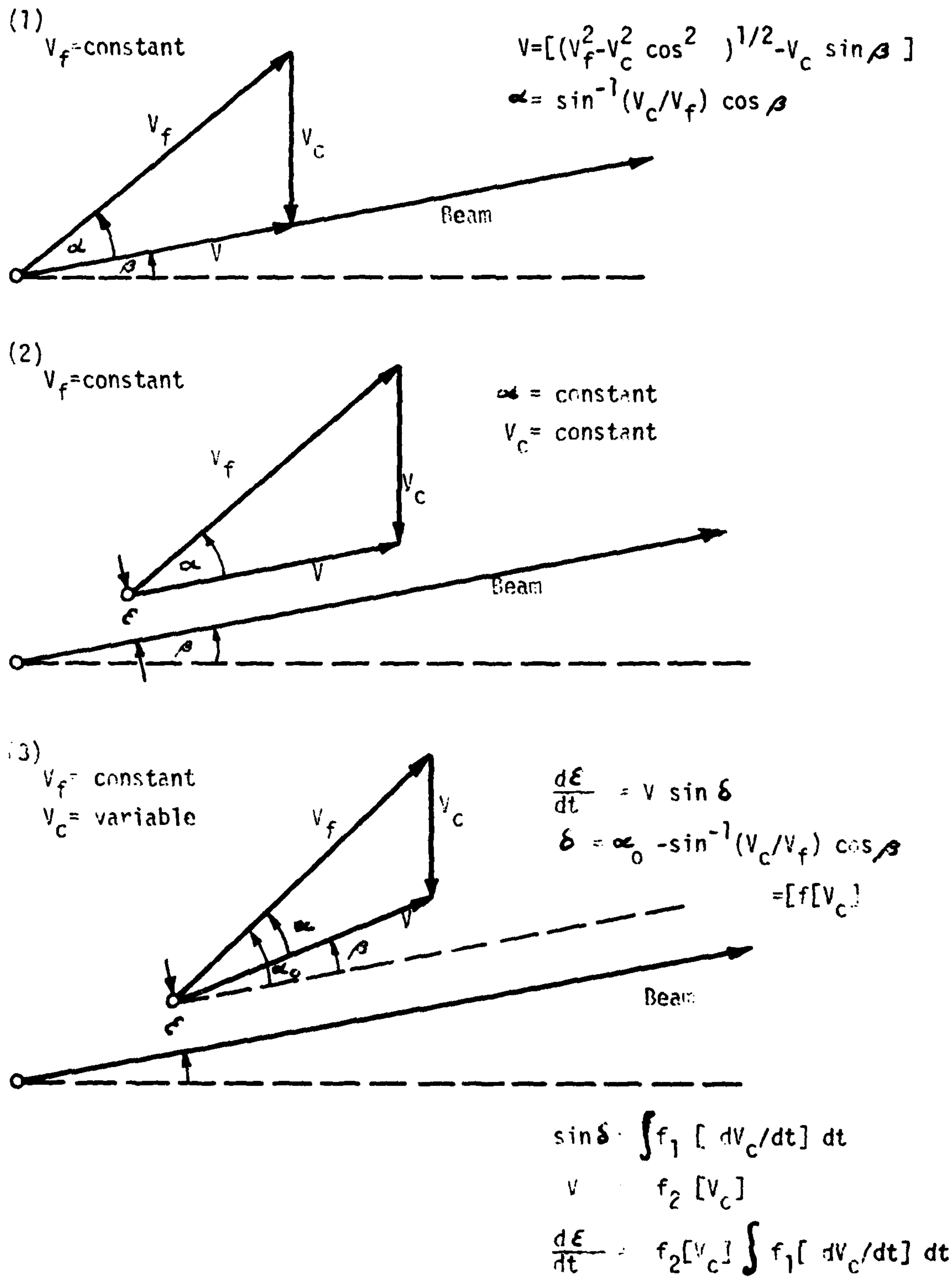


FIGURE C-3 RELATIONSHIPS FOR A BEAM-RIDING SYSTEM

measure ε and δ directly, in others it may be simpler to measure $d\varepsilon/dt$. and $d\varepsilon/dt$.

In the case of the ferry, the system must be able to handle large values of ε and δ, and if necessary to enter into an automatic search mode if the beam is "lost" entirely, in order to regain the beam.