SAFETY EVALUATION

OF THE

PUMP JET PROPULSION ASSEMBLY

FOR THE

MILITARY AMPHIBIOUS RECONNAISANCE SYSTEM

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1.0 PURPOSE. This report evaluates the safety factors associated with the Pump Jet propulsion assembly designed as a component for the Military Amphibious Reconnaissance System (MARS) engine used to power the Combat Rubber Raiding Craft (CRRC). This evaluation, in accordance with MIL-STD-882B, System Safety Program Requirements, covers the installation, operation, maintenance, and storage of the Pump Jet component to the MARS engines.

A Preliminary Hazard Analysis Of The Pump Jet Propulsion Assembly For Outboard Motors was performed and issued in a report dated 8 January 1992. The Preliminary Hazard Analysis (PHA) identified and analyzed the hazards associated with the Pump Jet propulsion assembly, classified the hazards according to their severity and frequency of occurrence, and recommended actions which would eliminate or reduce risk to an acceptable level. The PHA found that the Pump Jet was designed so that access during operation, servicing, and maintenance minimized personnel exposure to hazards and minimized risk created by human error in the operation and support of the equipment.

Ultimately, one must insure that safety, consistent with mission requirements, is designed into the Pump Jet propulsion assembly both as a hardware consideration and for logistics support.

2.0 SYSTEM DESCRIPTION. The Pump Jet propulsion assembly will be used as a replacement for the outboard propellers used with the MARS engine to power the CRRC - aka Zodiac inflatable boat (see Figures 1 and 2). The CRRC is used in amphibious reconnaissance operations involving the penetration of hostile shorelines. Teams of six persons and their equipment are deployed using the CRRC. Each team is transported from a host ship to shore where beaching and extended reconnaissance may be anticipated. The reliability, performance, and safety of the equipment in transiting to and from shore is a critical factor relating to mission success.

The MARS engine with outboard propellers was initially fielded by the Marine Corps in the late 1970's. Increased combat loads and increased ranges have resulted in modifications to the MARS engine; however, the hazards associated with outboard propellers have never been successfully resolved.

3.0 FUNCTIONAL/OPERATIONAL DESCRIPTION. The Pump Jet consists of an axial flow pump which is fully enclosed in a ducted housing much

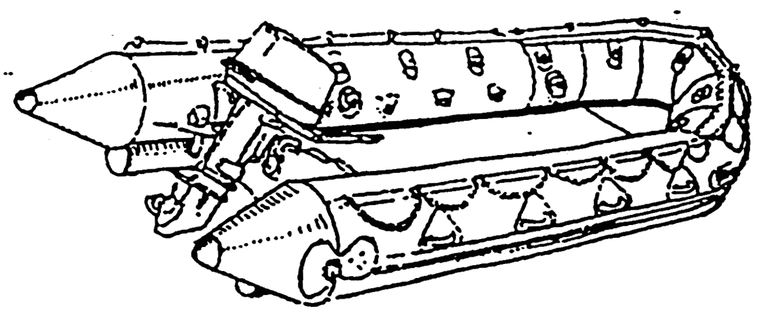

Figure 1. Combat rubber Raiding Craft (CRRC)

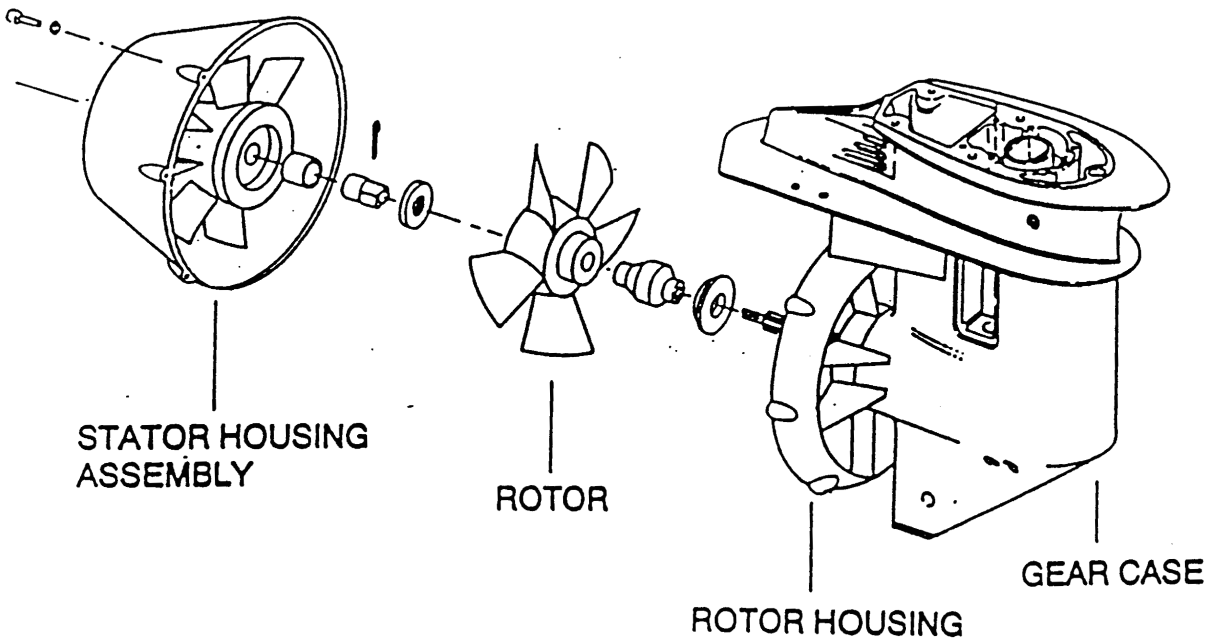

Figure 2. Pump Jet Propulsion Assembly for MARS Motor

in the same manner that the compressor section of a turbojet engine is enclosed by the engine nacelle (refer to Figure 2). The assembly consists of a forward housing to enclose the rotor, a rotor to develop the water jet, and an aft stator housing to maximize the thrust developed by the water jet. The rotor housing assembly is an integral part of the lower gear case assembly of the MARS engine. Consequently, no rotating parts of the pump jet are exposed to inadvertent contact by swimmers, scuba divers, or large underwater debris, as is the case with the potentially dangerous open propeller.

4.0 <u>DESIGN CONCEPT</u>. The design objective is to increase mission success of amphibious reconnaissance operations by reducing the generated noise signature and offering significant increases in team safety. While eliminating the possibility of personnel coming into contact with the propeller is primary, performance of the boats is also part of the safety issue. The Pump Jet must provide the CRRC with the capability to perform as effectively in all environmental conditions as the CRRC would with conventional propellers. Performance is measured in terms of stability, maneuverability, speed, endurance, and the survivability of the CRRC and its passengers. The ultimate goal is to eliminate the risk of laceration or trauma from any part of the MARS motor to personnel submerged in the surrounding water.

The order of precedence for satisfying system safety requirements and resolving identified hazards were taken from MIL-STD-882B and are as follows:

a. Design for minimum risk.

b. Incorporate safety devices.

c. Provide warning devices.

d. Develop procedures and training.

The primary safety concern with the existing MARS motor is the safety hazard from conventional unshielded propellers to personnel inadvertently coming into contact with spinning propellers during inserts/extracts. Previous hardware modifications designed to shield outboard motor propellers significantly degraded the mission and operational performance of the boat. When a ring guard was used as the shield for the outboard motor propellers the hazard risk actually increased because objects pulled into the motor tended to become trapped between the ring guard and propeller resulting in more severe damage to the personnel (in the case of limbs) and the motor (in case of debris). Speed, maneuverability, fuel economy, operational availability, and maintainability all suffered to an extent unacceptable for mission performance. The degraded maneuverability became a safety concern in itself.

Safety has been engineered into the design of the MARS motor to incorporate the following features:

a. an engine emergency stop lanyard to stop the engine if the coxswain falls overboard;

b. a quick kill button on the tiller to stop the motor in an emergency;

c. relocation of the gear shift lever for improved human/machine interface;

d. improved state-of-the-art ignition electronics.

The Pump Jet's rotor-stator design also has other advantages in that it is exceptionally well torque balanced and in it's overall propulsive efficiency, which approximates that of a conventional propeller.

5.0 SAFETY CERTIFICATION PROCEDURES. Table 1 identifies hazards categorized in the PHA and how these risks are evaluated for safety certification of the Pump Jet propulsion assembly.

Table 1. Safety Certification Procedures.

Hazard	Result	Classification	Evaluation
Danger to divers: > underwater > in dark.	Loss of digits Lacerations	10 Critical/Remote	By test.
Danger to coxswain: > fatigue > falls overboard > motor flies up	Trauma injury Loss of digits Lacerations	11, 15 Marginal/Occasional Critical/Improbable	By test and analysis.
Danger to passengers: > fatigue > falls overboard > motor flies up	Trauma injury Loss of digits Lacerations	11, 15 Marginal/Occasional Critical/Improbable	By test and analysis.
Danger to mechanic: > inserts hand > inserts tool > exposure to blades	Loss of limb Loss of digits Lacerations	10 Critical/Remote	By analysis.
Damage to boat: > runs into debris > boat flips	Personnel death Personnel loss System loss System damage	11, 12 Marginal/Occasional Catastrophic/ Improbable	By test and analysis.

Testing was performed to the following procedures and criteria (refer to Table 2). Tests were initially conducted by field users during May-June 1991. Where inadequacies were noted tests were followed up in May 1992 after design improvements. These tests compared the results of CRRC's equipped with conventional propellers and CRRC's equipped with Pump Jet propulsion assemblies. The results indicate that the Pump Jet can perform comparably or better than conventional propellers.

Table 2. Test Procedures And Criteria.

TEST PROCEDURE	CRITERIA	RESULTS
Acceleration and maintenance of speed.	In Sea State 1, while carrying a full load, accelerate from 0 knots to 8 knots and maintain speed.	Pass
Handling in open sea.	The ability to propel through open seas and through the surf zone. "Skylining" of boat as waves pass under it. Also, loss of control of boat when there is not sufficient propulsion to power through the surf.	Pass
Insertion/extraction maneuvers in all surf conditions.	Perform in Sea State 1 conditions.	Pass
Capabilities in beaching operations.	Launch from amphibious ship. Simulate variety of recon/raid operations. Minimize noise level.	Pass
Operating in surf conditions with debris.	Debris to consist of kelp, tree branches, sand, and rocks.	Pass
Towing	One fully loaded CRRC towing another fully loaded CRRC.	Pass

While tests were conducted, no divers experienced any lacerations from the use of the Pump Jet; nor did the coxswain experience any unusual or premature fatigue from operating the CRRC equipped with the Pump Jet.

The use of the Pump Jet has no deleterious effect on the stability of the CRRC during thrust propulsion. The CRRC will maintain an on-plane status. Like propeller-driven CRRC's, the weight of loads, their positioning on the boat, and the possibility of the shifting of loads have an effect on the CRRC's ability to go on-plane, but the use of the Pump Jet does not cause any unusual practice.

5.1 Risk Analysis.

5.1.1 Confidence level of operators and divers. Because the rotary blades of the Pump Jet are enclosed in a housing, as opposed to the open and exposed propeller blades, the confidence level of swimmers and divers in the surrounding water will not diminish, but will increase as compared to CRRC's powered by motors with conventional propellers.

5.1.2 Training. Fielding the I-MARS motor configured with the Pump Jet will not introduce a requirement for new training skills to the Marine Corps. There will be a requirement for maintenance personnel to become familiar with a new component to the small boat outboard motors. Technical Manuals for the Pump Jet will have to be written. Arrangements have already been made for Marine Corps schools (through the services of a contractor) to add new material to their training course to accommodate the adoption of the Pump Jet as standard equipment. Such familiarization will not require new maintenance skills.

5.1.3 Maintenance servicing. The Pump Jet will not present any new safety hazards, which do not already exist with the propeller-driven CRRC, to maintenance personnel during corrective maintenance, or to users when conducting preventive maintenance. Since the Pump Jet has a rotary vane, the same precautions must be observed with the Pump Jet when the Rotor Housing is removed as when working on the present configuration of the CRRC with an open, exposed propeller. Once the Stator Housing Sub-assembly of the Pump Jet is removed, exposing the rotor blades, the rotor presents the same hazard (and no greater) as the always open and exposed propeller of the present MARS configuration.

5.1.4 Operational risks. While the hazard of a diver getting digits sucked into the rotor housing is always present in the case of the Pump Jet, it does not present as great a danger as with an open, exposed propeller. The fixed vanes of the rotor housing are likely to prevent obstacles from protruding into the rotary vanes. They would also provide some degree of warning to the diver of the omnipresent danger, since there is some degree of clearance between the fixed vanes at the opening of the housing and the rotary vanes which have an interior location.

6.0 CONCLUSIONS. An evaluation of the safety factors affecting the Pump Jet propulsion assembly for the MARS motors for use with CRRC are listed below. These conclusions reaffirm the conclusions reached in the Preliminary Hazard Analysis of the Pump Jet.

a. There are no hazards which are classified as unacceptable thereby requiring a redesign of the Pump Jet propulsion assembly.

b. There are no hazards classified as undesirable.

c. Only one hazard has been identified which could be classified as Catastrophic - May cause death or system loss. However, its frequency of occurrence is Improbable; and, in any event this hazard - CRRC runs into debris - is present and just as dangerous as the present operating system with the propeller-driven MARS motor.

d. No hazards have been identified which could be classified as Critical (May cause severe injury or damage) with a frequency of occurrence which would make them either unacceptable or undesirable (i.e., Frequent, Probable, Occasional).

e. The hazards which are listed are either not severe or not of a frequent nature.

f. The hazards which are listed are less likely to occur with the Pump Jet assembly than with the present propeller-driven MARS motor; and, therefore present a reduced risk because of their lower frequency of occurrence.

g. Although there are no new training requirements as a result of the introduction of the Pump Jet propulsion assembly, training should receive emphasis in order to provide proper and adequate safeguards to the hazards which remain.

h. The configuration of the Pump Jet, in comparison to the present configuration of the propeller-driven MARS motor, reduces the risk of danger to personnel.

i. The Pump Jet configuration adequately protects the rotor from accidental contact by personnel.