

NAVY OMNI-DIRECTIONAL VEHICLE (ODV) DEVELOPMENT PROGRAM 2514

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ABSTRACT

The omni-directional vehicle (ODV) development program sponsored by the Office of Naval Research at the Coastal Systems Station has investigated the application of ODV technology for use in the Navy shipboard environment. ODV technology as originally received by the Navy in the form of the Cadillac-Gage Side Mover Vehicle was applicable to the shipboard environment with the potential to overcome conditions of reduced traction, ship motion, decks heeled at high angles, obstacles, and confined spaces. Under the Navy program, ODV technology was investigated and a series of experimental vehicles were built and successfully tested under extremely demanding conditions. The ODV drive system has been found to be applicable to autonomous, remotely, or manually operated vehicles. Potential commercial applications include multi-directional forklift trucks, automatic guided vehicles employed in manufacturing environments, and remotely controlled platforms used in nuclear facilities or for hazardous waste clean up tasks.

NAVY ODV DEVELOPMENT

The Navy ODV development program has investigated the application of ODV technology for use in the shipboard environment for cargo and ordnance handling. ODV technology as received by the Navy in the form of the Cadillac-Gage vehicle had the potential to overcome the limitations of existing vehicles under conditions of reduced traction, ship motion, decks heeled at high angles, obstacles, and restricted spaces. Development concerns focused on omni wheel complexity, footprint pressure, and traction; vehicle control, reliability, cost, maintainability, and autonomous and teleoperated vehicle control. Under the Navy program, a series of experimental vehicles were built and tested.

The omni wheel was originally patented by a Swedish inventor Bengt Ikon in 1973. The omni wheel and its operating principle is shown in Figures 1 and 2. The ODV is a four wheel drive system where each of the non-steerable wheels has its own drive motor. The omni-directional wheel allows the vehicle to travel in any direction, rotate about its axis, or to do both simultaneously (see Figure 3). Omni wheels are not steered as the plane of rotation is fixed in reference to the chassis. Mounted at a 45 degree angle to the wheel plane of rotation are a series of passive elliptical rollers. When a wheel is rotated, the resulting motion tends to move the wheel on the ground at a 45 degree angle to its plane of

rotation. By adding the individual motion created by each wheel, the vehicle can move in any desired direction. Vehicle speed and direction is controlled by a three axis joystick. Responding to the joystick, microprocessor-based algorithms control the rotation of each wheel to achieve the desired vehicle motion. The true three degree of freedom movement provided by the omni wheel, the capacity to operate under reduced traction conditions, and over substantial obstacles makes the ODV an ideal platform for robotic and teleoperated vehicles requiring high level control systems.



FIGURE 1. OMNI-DIRECTIONAL WHEEL

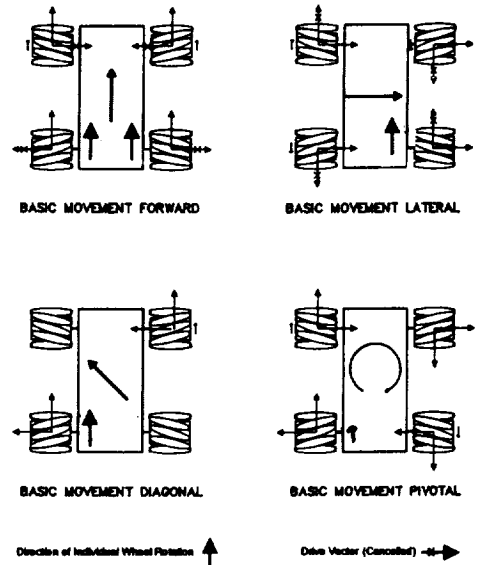


FIGURE 2. OMNI-DIRECTIONAL WHEEL OPERATING PRINCIPLE

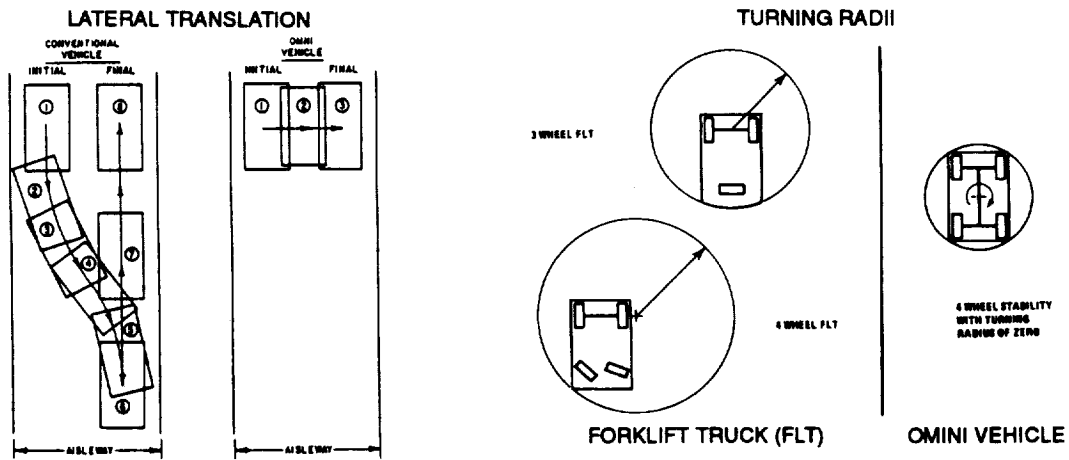


FIGURE 3. OMNI-DIRECTIONAL WHEEL MANEUVERABILITY VERSUS CONVENTIONAL VEHICLES

ODV AND ALL-WHEEL-STEERED VEHICLE COMPARISONS

Other high maneuverability drive systems including existing Navy multi-directional forklift trucks were compared with the ODV. This investigation found that the All-Wheel-Steered (AWS) vehicle was the only drive system capable of producing maneuverability approaching that of the ODV, and capable of being used in the shipboard environment. Two AWS sideloading forklift trucks have been used onboard Navy ships. It was established that the existing Navy AWS multi-directional vehicles had a number of limitations not shared by the ODV including:

- a. Limited maneuvering capability
- b. Mechanical complexity
- c. Difficult to operate and repair
- d. Scuffing damage to tires and deck non-skid surfaces

Complexity. The omni wheel is more complex than a conventional wheel. However, when conventional wheels are coupled to a suspension, drive, and steering system to produce a AWS vehicle, the vehicle is more complex than the ODV. Thus when addressing complexity and reliability, both wheel and vehicle complexity must be considered. With the exception of the wheel, the design and fabrication of an ODV is straightforward with most of the components available off-the-shelf. Mechanically, the ODV is a uncomplicated system: four identical drive units; the omni wheels; a simple suspension system; and a battery or diesel engine power source. Figure 4 illustrates the relative simplicity of the ODV mechanical and electrical design.

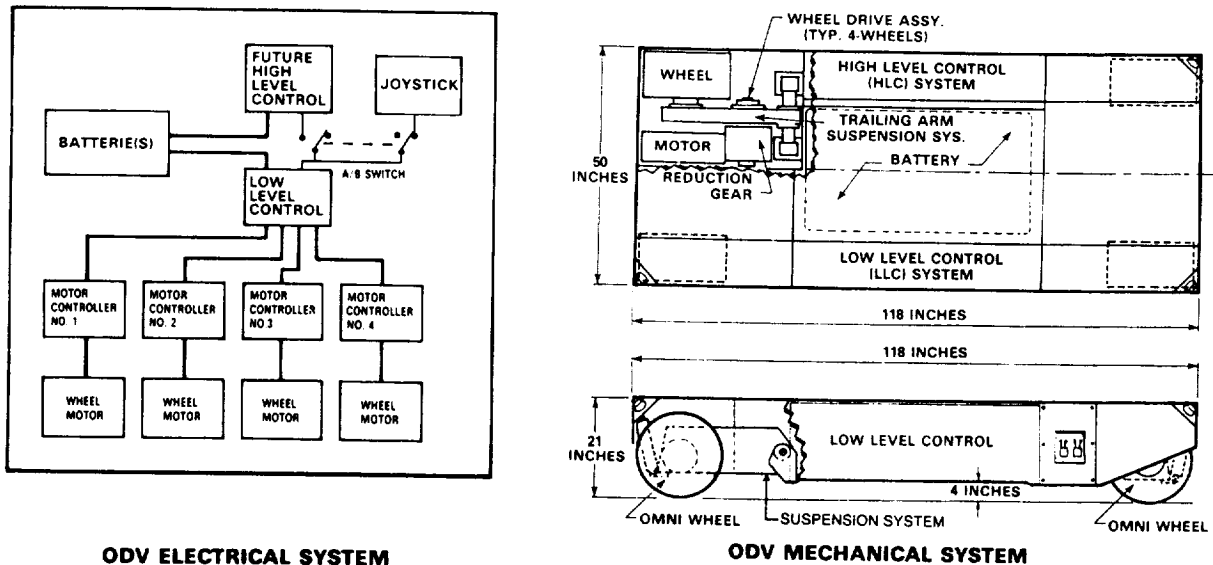


FIGURE 4. ODV MECHANICAL AND ELECTRICAL SYSTEMS

Maintenance. Maintenance for ODV and AWS vehicles must be considered on a system basis rather than on the wheel alone. The 19-year old Cadillac-Gage vehicle has never suffered a failure associated with the wheel even after having been run under adverse conditions including: sand, water, and mud. Three factors concerning wheel wear and failure should be noted. First, the omni wheel is essentially non-scuffing. Second, the time that the individual roller contacts the ground is only a portion of a revolution of the wheel. Third, a vehicle can be operated with a drive unit inoperative and the wheel free to rotate or even with a wheel removed, if the vehicle is suitably balanced.

The ODV drive system as seen in Figure 4 consists of four identical drive units; omni wheels, simple suspension system, a battery, and compact, easy to troubleshoot control electronics. Taken together these components equate to a low maintenance system. The omni wheel is more complex than a conventional wheel; however, the rest of the ODV is robust and straightforward. Conversely, steering, drive, and control mechanisms of the AWS vehicle are complex and present a continuing maintenance burden.

NAVY ODV PLATFORMS

A family of conceptual ordnance and cargo handling vehicles based on the omni drive system was developed by the Coastal Systems Station. An 8,000-pound capacity sideloading forklift truck with 18-inch omni wheels was selected for advanced development. This vehicle, the Omni-Directional Ordnance Handler (ODOH), is designed to transport long, heavy missiles and other ordnance down narrow passageways onboard Navy ships. A preliminary design for the ODOH (Figure 5) has been completed.

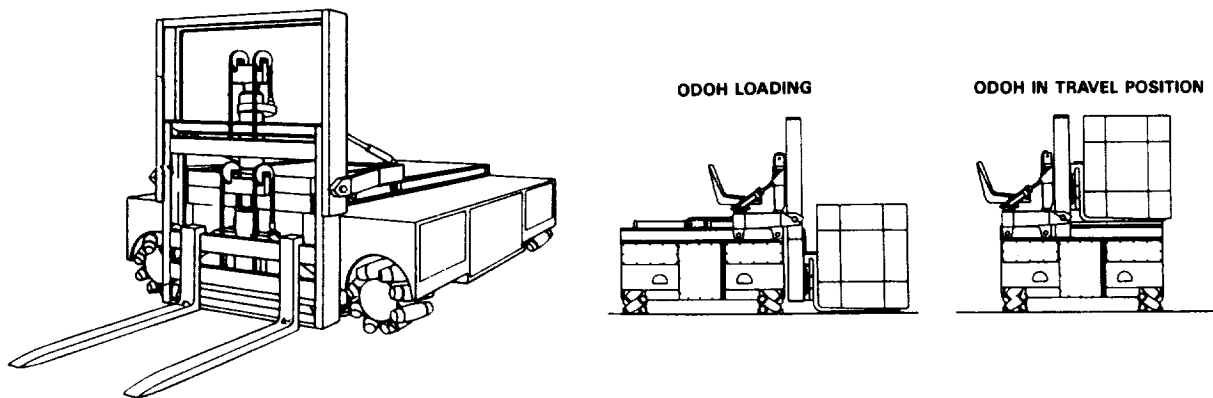


FIGURE 5. OMNI-DIRECTIONAL ORDNANCE HANDLER (ODOH)

A small ODV model (Figure 6) was fabricated to test the electronic control system and to illustrate the omni wheel principle of operation. This model clearly demonstrated the simplicity of operating an ODV, its ability to negotiate obstacles and to maneuver in extremely confined spaces.

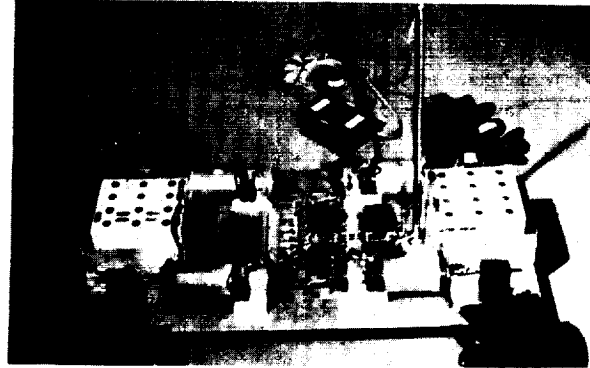
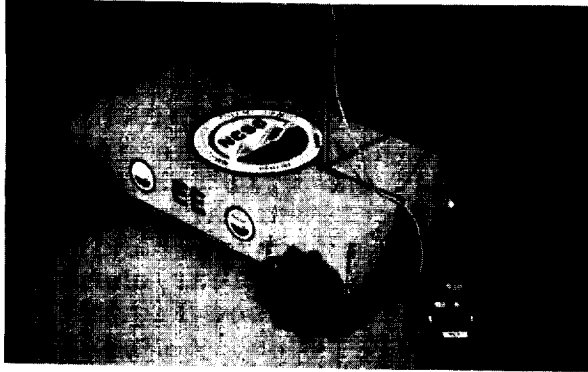


FIGURE 6. OMNI-DIRECTIONAL VEHICLE MODEL

To provide a full-scale Omni-Directional Test Platform (ODTP) (Figures 7a and 7b), the original Cadillac-Gage ODV, (Figure 7c), was modified by: removing the operator seat and other structure, leaving only a simple transport platform; adding an electronic control system to resolve the deficiencies of the original hydraulic system; and replacing the gasoline engine with a battery powered, eight-horsepower electric motor so that the vehicle could be operated indoors and below decks.



FIGURE 7A. OMNI-DIRECTIONAL TEST PLATFORM (ODTP)



FIGURE 7C. CADILLAC-GAGE VEHICLE

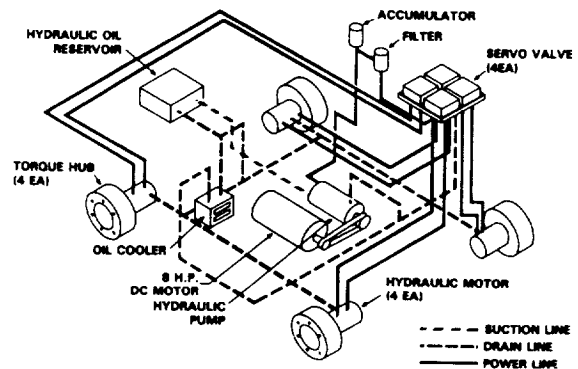


FIGURE 7B. OMNI-DIRECTIONAL TEST PLATFORM (ODTP) DIAGRAM

A proof-of-concept Multi-Purpose Autonomous Vehicle (MPAV) Platform (Figure 8) was developed for the Naval Air Warfare Center (NAWC) during 1992-93 to explore the use of ODV technology as a universal platform supporting the use of robotic systems on

- a. Vehicle control and traction tests on ice in a skating rink and under cold weather conditions.
- b. Operational tests on a dynamic ship motion simulator.
- c. Static tilt table tests to validate the capability to operate at extreme deck angles.
- d. Missile handling in a simulated shipboard environment to demonstrate the capability of an ODV to transport long, heavy missile loads in restricted spaces.

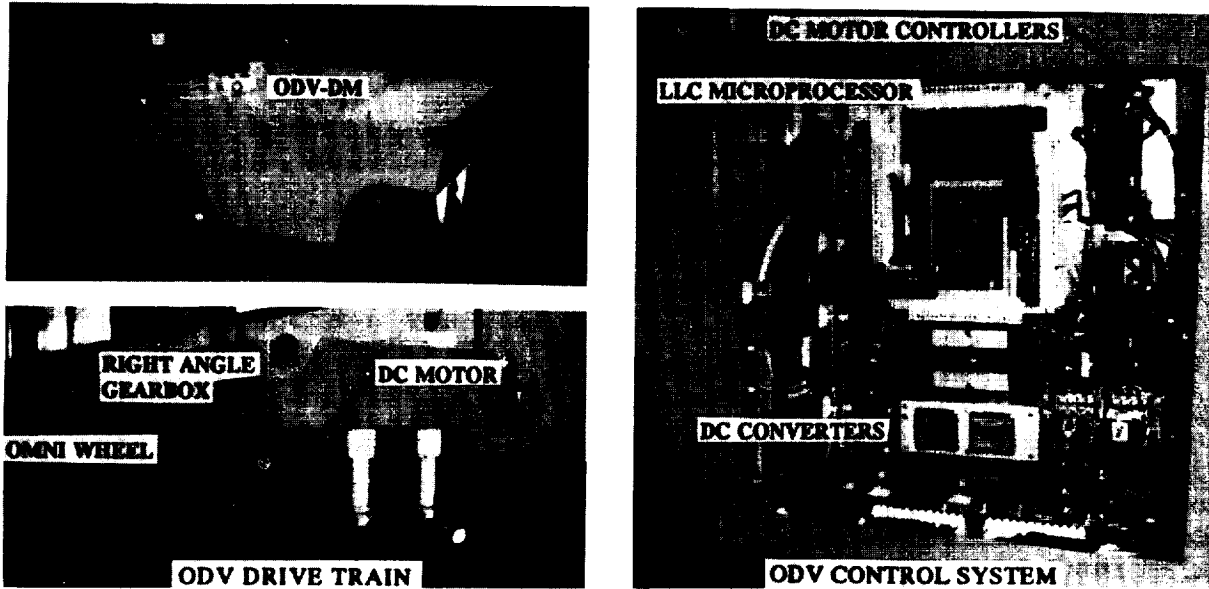


FIGURE 10. OMNI-DIRECTIONAL VEHICLE DEMONSTRATION MODEL (ODV-DM)

These tests have validated the capability of the ODV to operate under adverse shipboard conditions (i.e. reduced traction on wet/icy decks with ship motion and decks heeled at high angles).

Traction Test. The full-scale ODTP, small ODV model, and a conventional forklift truck were operated on ice in a skating rink (Figure 11) to evaluate the capability of an ODV to maneuver and to

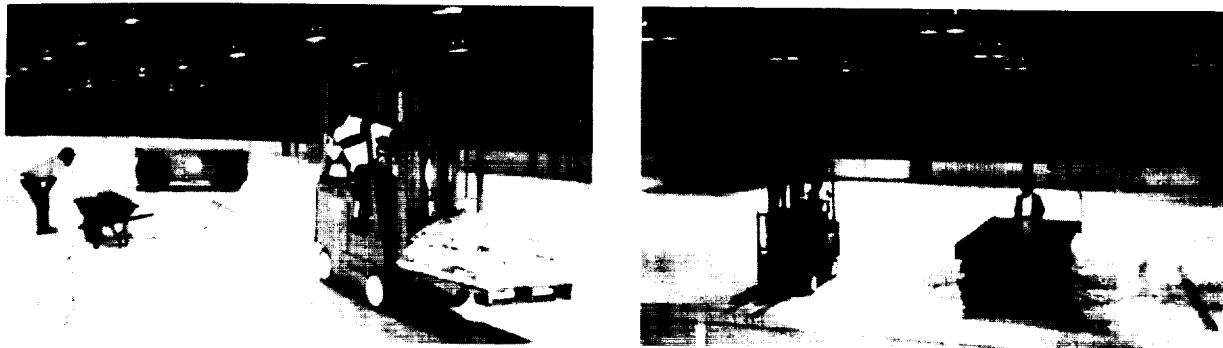


FIGURE 11. ODV ICE RINK TRACTION TESTS

retain control under low traction conditions, and to compare performance with that of a conventional forklift truck. The tests indicated that both ODVs had adequate traction to be fully controllable and capable of performing all maneuvers. The ODTP significantly outperformed the forklift truck in terms of traction and controllability.

Army Cold Weather Traction Test. Tests conducted by the Army further confirmed the ability of the ODV to operate on ice, snow, and wet surfaces. From the test results the following conclusions were drawn:

- a. The omni wheel significantly outperforms a conventional, non-pneumatic tire in driving traction and control on a smooth ice surface.
- b. The omni-directional wheel shows a broad peak traction region on a drawbar-pull versus slip curve, with a desirable slow tapering off of force after the peak value is reached. The fact that it has a broad range of slip levels where peak and near-peak traction occurs makes it very "user friendly" and forgiving to operators.

Ship Motion Test. During simulated ship motion tests the ODTP with a 4,000 pound load was operated forward, backward, sideways, and rotated in place. Motions to five degrees roll and three degrees pitch were induced. Neither the vehicle nor the operator experienced any control problems.

Static Tilt Table Tests. Tilt table tests as required for forklift trucks were conducted (Figure 12) to validate the capability of the ODTP to operate without skidding. The ODTP maintained position without slip under the following extreme conditions of static tilt:

- 26 degrees, ODTP perpendicular to slope
- 23 degrees, ODTP parallel to slope
- 19 degrees, ODTP 45 degrees to slope

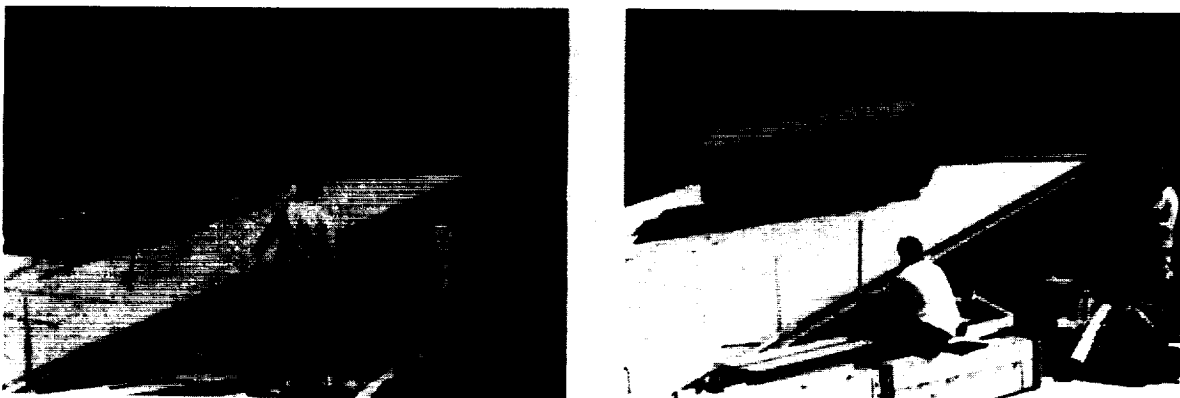


FIGURE 12. ODV TILT TABLE TESTS

Missile Canister Handling. Missile canister handling demonstrations were conducted with the ODTP (Figure 13) to validate the capability of an ODV to transport long, heavy, loads in restricted shipboard spaces. The ODTP performed this mission very efficiently and without difficulty.

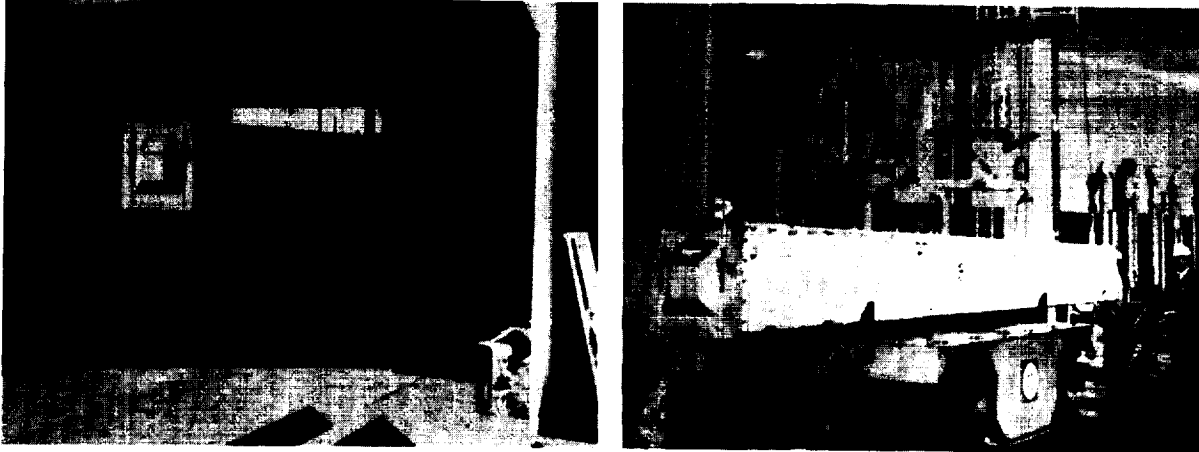


FIGURE 13. ODV MISSILE CANISTER HANDLING TEST

MPAV-ODV Functional Test. In September 1992, tests of the NAWC MPAV-ODV were conducted to evaluate vehicle's capability in terms of maneuverability, maintainability, and operability (see Figure 14). Fifteen individuals operated the vehicle after a brief description of the controls. After several minutes of practice, operator proficiency was established and complicated movements were achieved. This observation reinforces one of the primary benefits of the ODV (i.e. the vehicle is capable of complex motions while retaining a simple, user friendly operator interface). This feature is extremely important for man-in-the-loop, teleoperated, or autonomous vehicle operations.



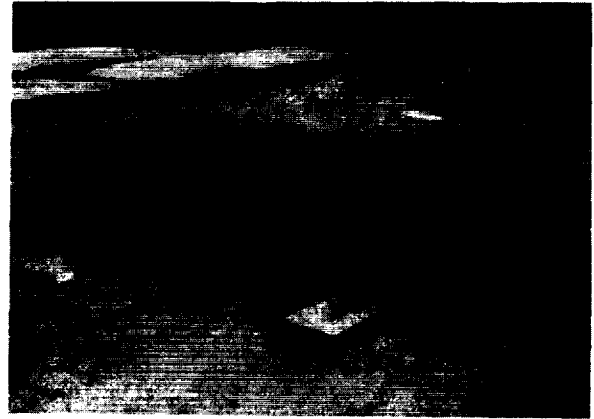
PRECISION MANEUVERING DEMONSTRATION

DRAWBAR PULL MEASUREMENT AT 90°

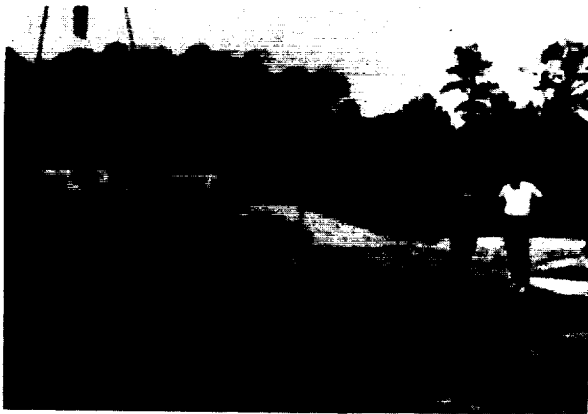
FIGURE 14. MPAV-ODV FUNCTIONAL TEST



SPEED MEASUREMENT AT 45°



**NEGOTIATING OBSTACLES
(3" BOARD, WIRE, ROPE, CHAIN)**



MANEUVERING LOADED ON 15° RAMP



OVERLOAD TESTS (4900 lbs)

FIGURE 14. MPAV-ODV FUNCTIONAL TEST (Continued)

CONCLUSIONS

Experience with the development of the full-scale ODTP and the recent fabrication and testing of the MPAV-ODV and ODV-DM has demonstrated that ODV technology can be implemented into a practical, rugged vehicle utilizing off-the-shelf components.

As a result of Navy R&D efforts, ODV technology has been validated for applications where maneuverability, control, traction, and obstacle negotiation are required. The ODV is well suited for use in the commercial manufacturer and warehousing environment as well as in nuclear facilities or other hazardous areas.