Naval Surface Warfare Center
INDIAN HEAD DIVISION

DISTRIBUTED EXPLOSIVE TECHNOLOGY - WEAPON SYSTEM SIMULATION

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Abstract

The Naval Surface Warfare Center, Indian Head Division (NSWC/IH) has pioneered a new class of weapons systems called "Distributed Explosive Technology" (DET). These weapons systems are being developed for clearing land or aquatic mines from a battlefield or surf zone. These systems consist of a large net–like structure called the "array." (Figure 1)

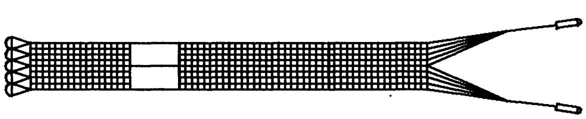

Figure 1. Typical DET System Configuration

The array is comprised of explosive rope material, and is designed to cover a large area on the battlefield. Remote detonation of the array triggers sympathetic detonation of all nearby mines. The array is towed downrange and into place by dual rocket motors launched from a location safely behind the battlefield.

In 1991, NSWC/IH began using ADAMS for performing full 3–D dynamic simulations of DET–type mine countermeasures weapons. Previously, ballistic analyses of the systems had been performed with two–dimensional dynamics software. The 2–D software was unable to account for the complex effects of net aerodynamics and elasticity on the flight dynamics of the DET systems. ADAMS offered a significant level of customization in the simulation environment, while replacing the 2–D software with commercially–proven, robust code. To transform the complex DET system into a practicable model, a lumped–mass approach was devised, in which the DET array components are represented in ADAMS as a network of masses connected by viscoelastic rope elements. The governing characteristics of the DET system components were then determined and modeled using a combined analytical–experimental–numerical approach which features:

- In conjunction with MDI Consulting Services and the University of Michigan, the complex aerodynamics of the DET systems were investigated in an extensive series of wind tunnel tests. Based on the wind tunnel data, an appropriate computational model was devised and linked with ADAMS using a custom VFOSUB. This joint effort was the first known study of net aerodynamics.
- In conjunction with MDI Consulting Services and Texas A&M University, the viscoelasticity of the array ropes was investigated experimentally, and an appropriate constitutive relationship was fit

to the data and implemented in ADAMS with a custom SFOSUB.

- In conjunction with MDI Consulting Services and the University of Michigan, the aerodynamic characteristics of the rocket motors were determined in the wind tunnel. The wind tunnel data was fit to the USAF DATCOM rocket model and implemented in ADAMS using a custom GFOSUB.

Current and future features of the DET models add significantly to the analysis capability ADAMS offers for DET simulations:

- An Energy Tracking Toolkit, a combination of differential equations and internal access to the ADAMS code which is used to compute the energy in DEMNS system components.
- A true point mass element, which when used to model array nodes will greatly speed up computation.
- ADAMS/IH, which will be a completely customized ADAMS/View-based pre-processing, analysis, and post-processing tool.
- Hydrodynamic Module, which will model the fluid-structure interactions of the DET systems launched from a bobbing craft and landing in water, using a combination of experimental data, analytical models, and an ADAMS VFOSUB.

Using the modeling techniques developed for DET systems, the ADAMS models of the DET systems are able to successfully predict flight trajectories and in-flight rope tensions. This information is used by NSWC/IH to support the DET development process both by providing guidance for future designs, and also by providing positioning information prior to flight tests.

Through a close partnership between NSWC/IH and MDI, significant insight into the design challenges of DET mine countermeasures systems has been achieved. Specifically, this has resulted in:

- customized weapon simulation tools
- experimental test capabilities
- model validation techniques, and
- improved engineering design processes

thus resulting in a true virtual prototyping simulation environment to improve mine countermeasure system design.

Naval Surface Warfare Center
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DISTRIBUTED EXPLOSIVE TECHNOLOGY: SHALLOW WATER MINE COUNTERMEASURES WEAPON SYSTEM SIMULATION

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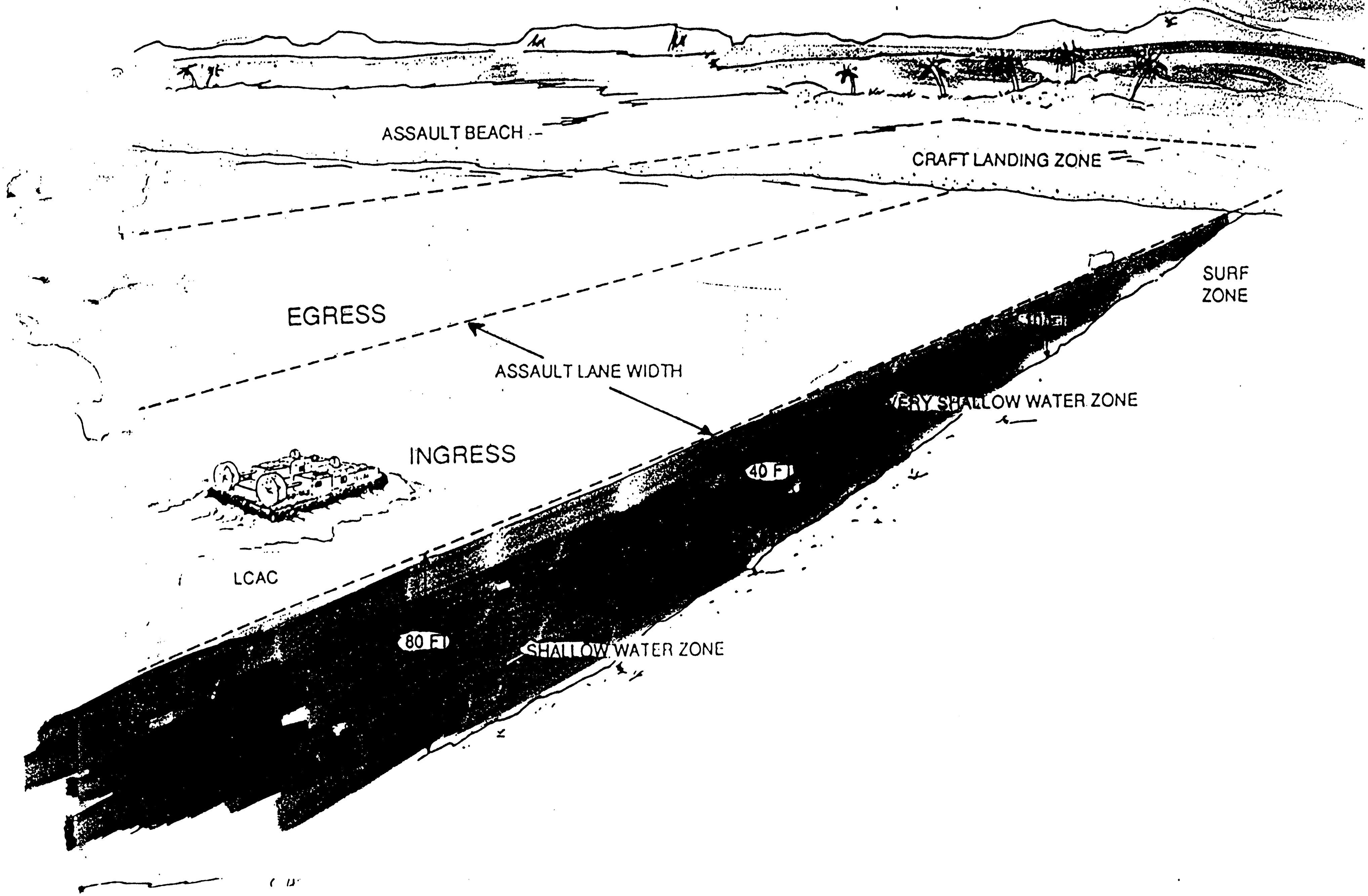
SHALLOW WATER MINE COUNTERMEASURES MISSION



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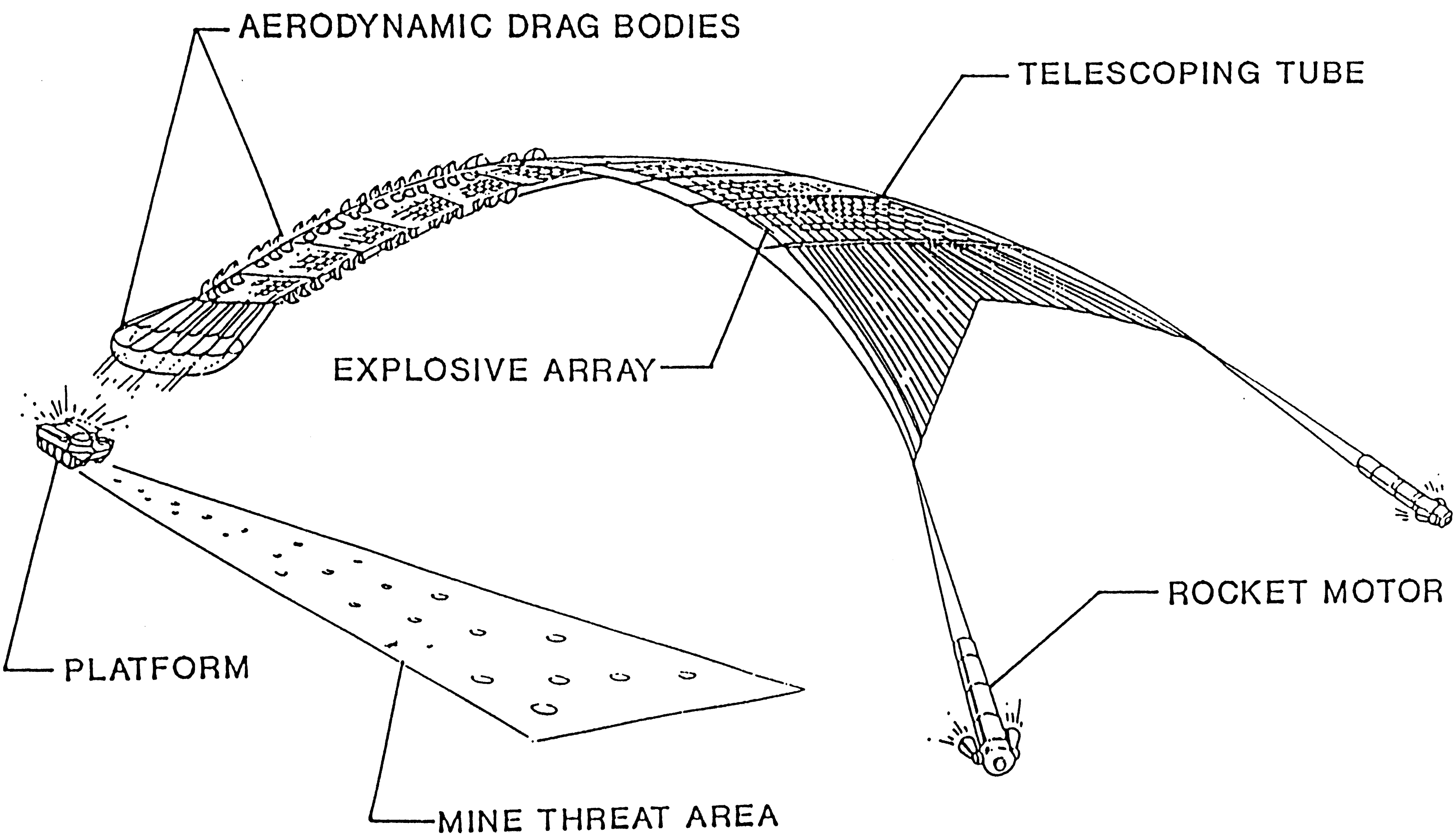
DISTRIBUTED EXPLOSIVE MINE NEUTRALIZATION SYSTEM

DEMNS

DISTRIBUTED EXPLOSIVE MINE NEUTRALIZATION SYSTEM



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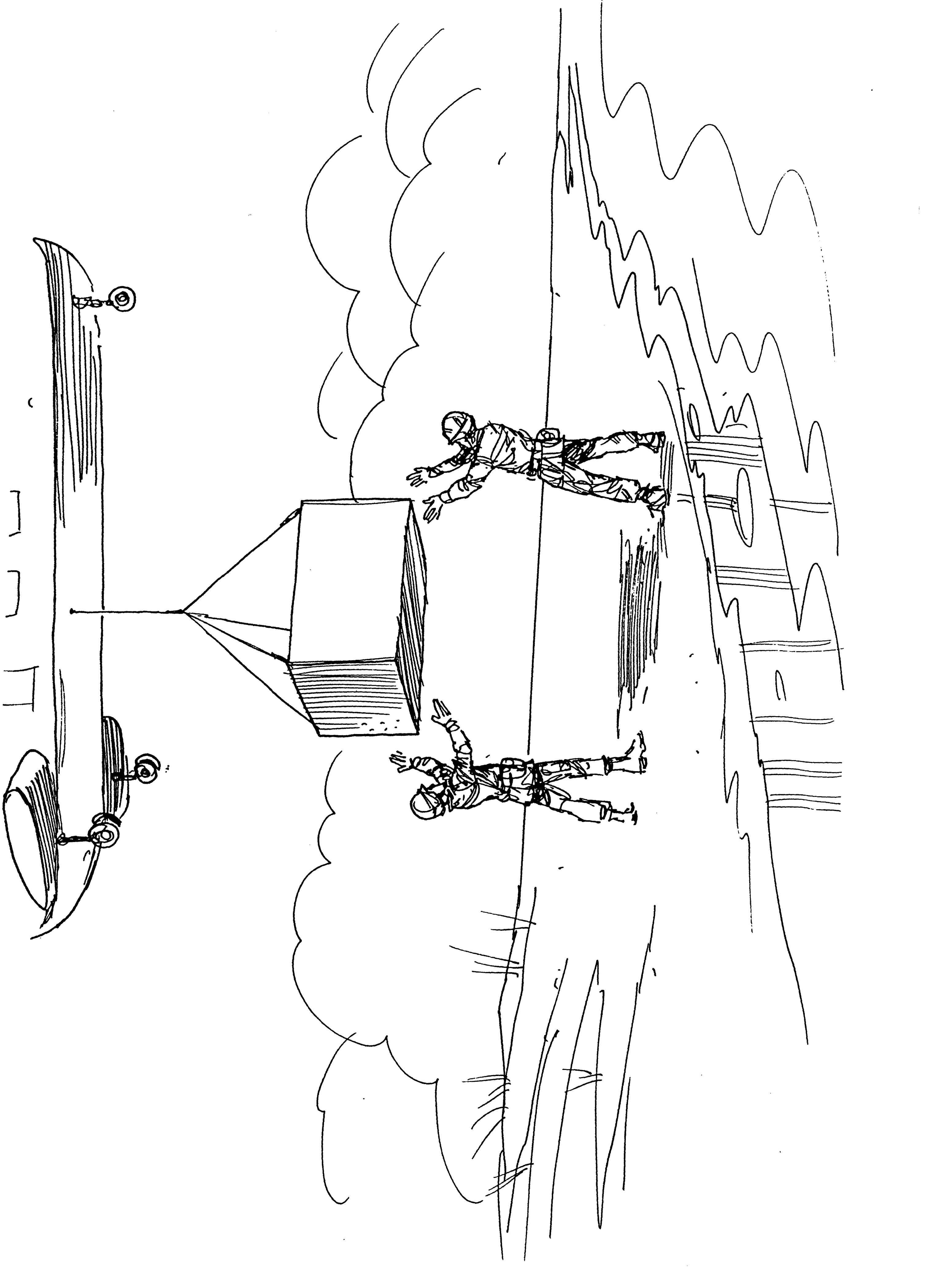
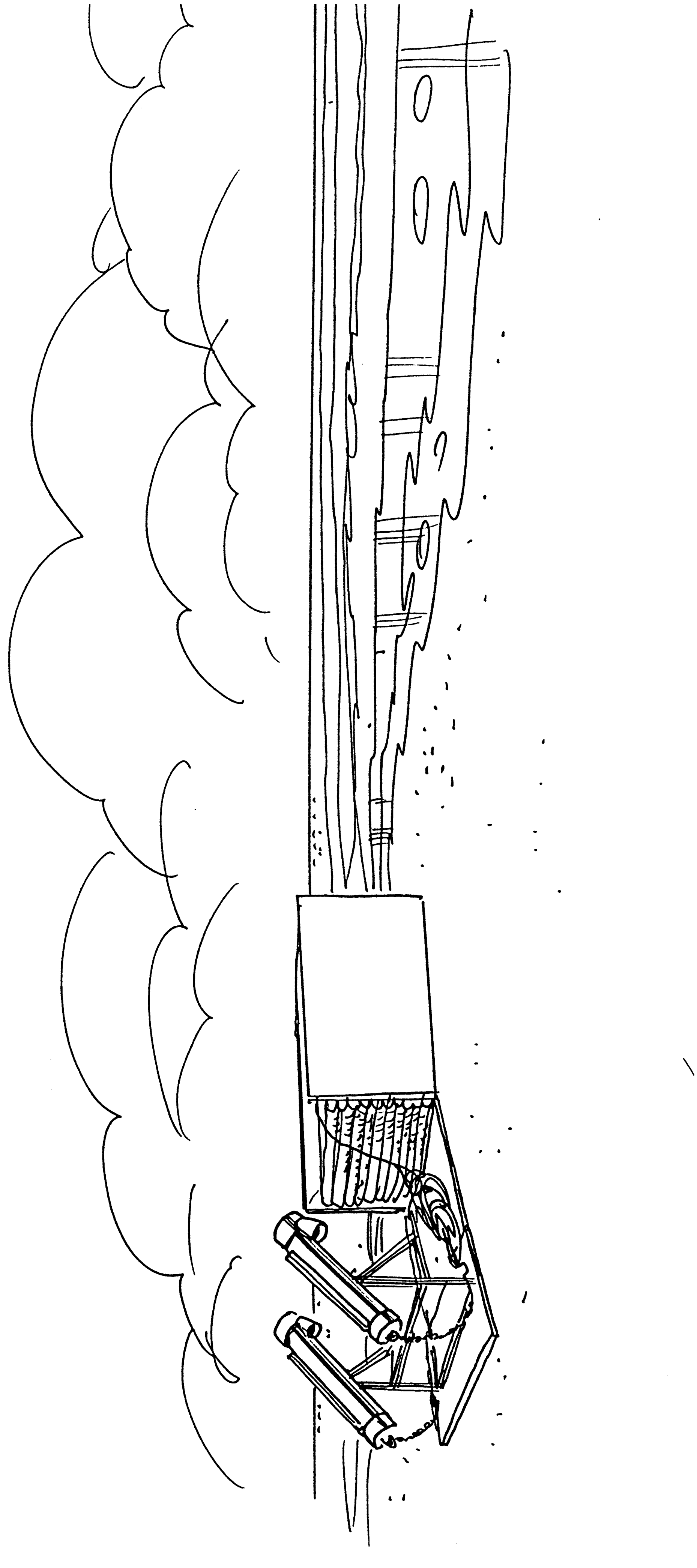
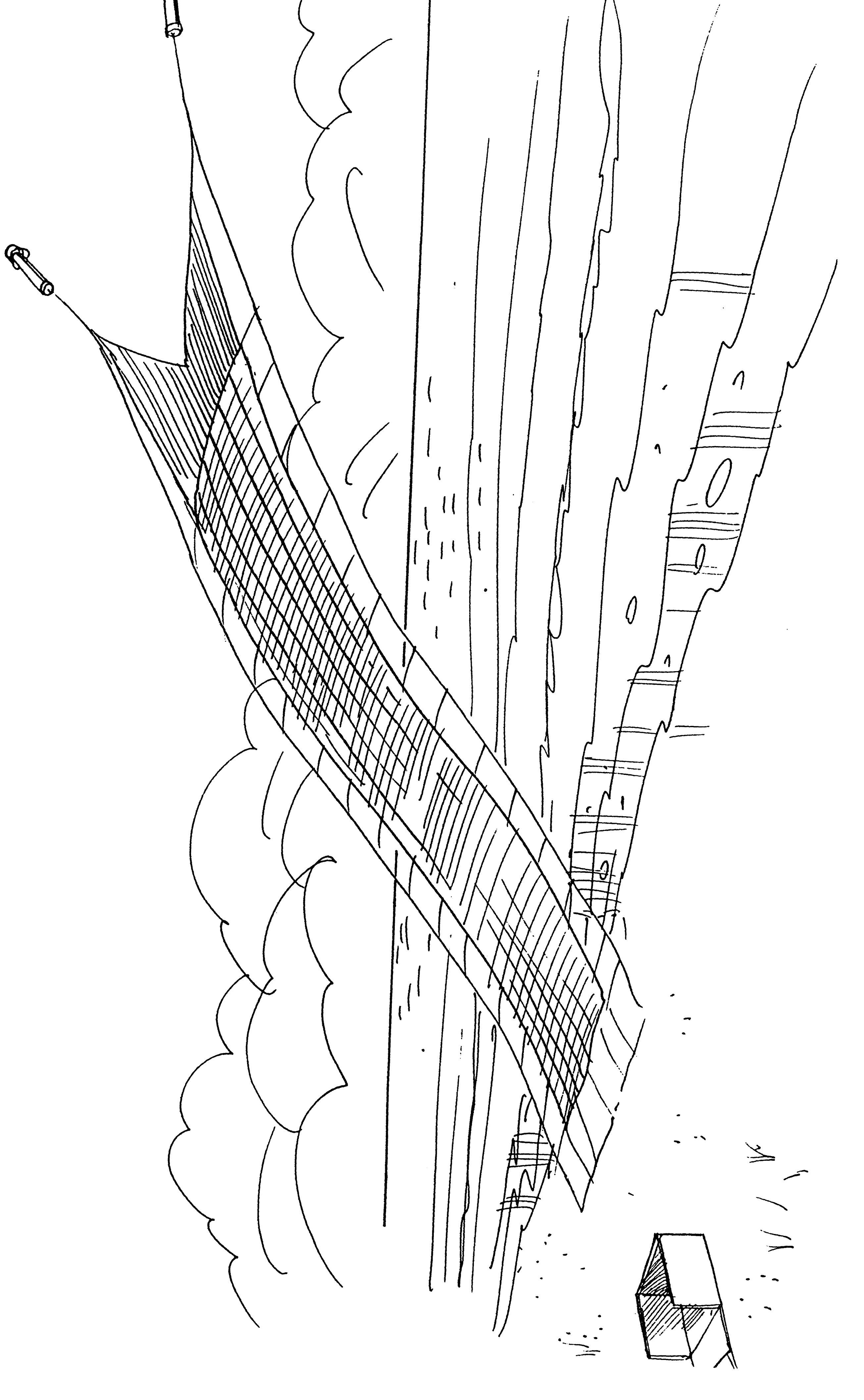
DET

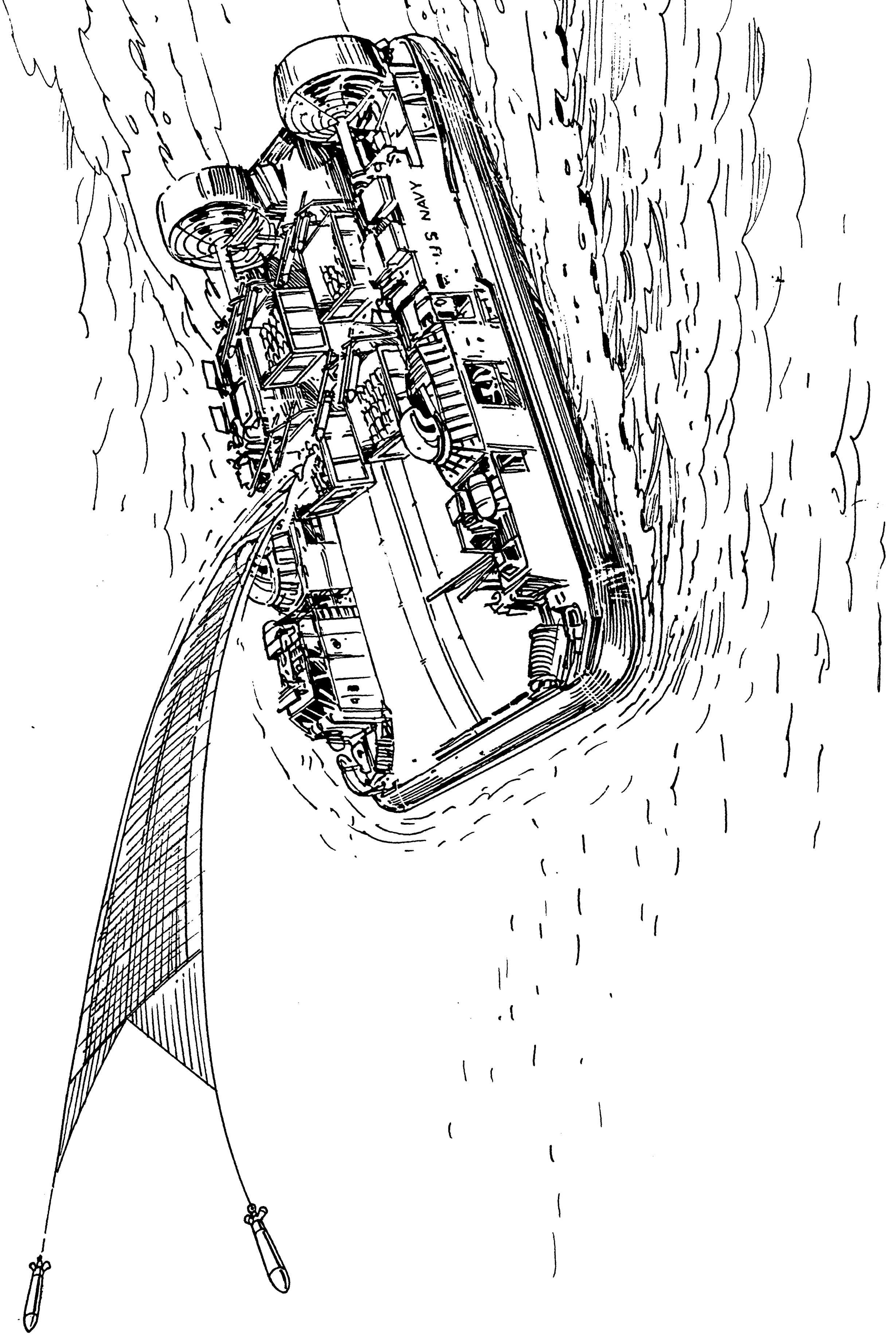






EXPLOSIVE NEUTRALIZATION - ADVANCED TECHNOLOGY DEMO SURFZONE ARRAY

EN-ATD SZA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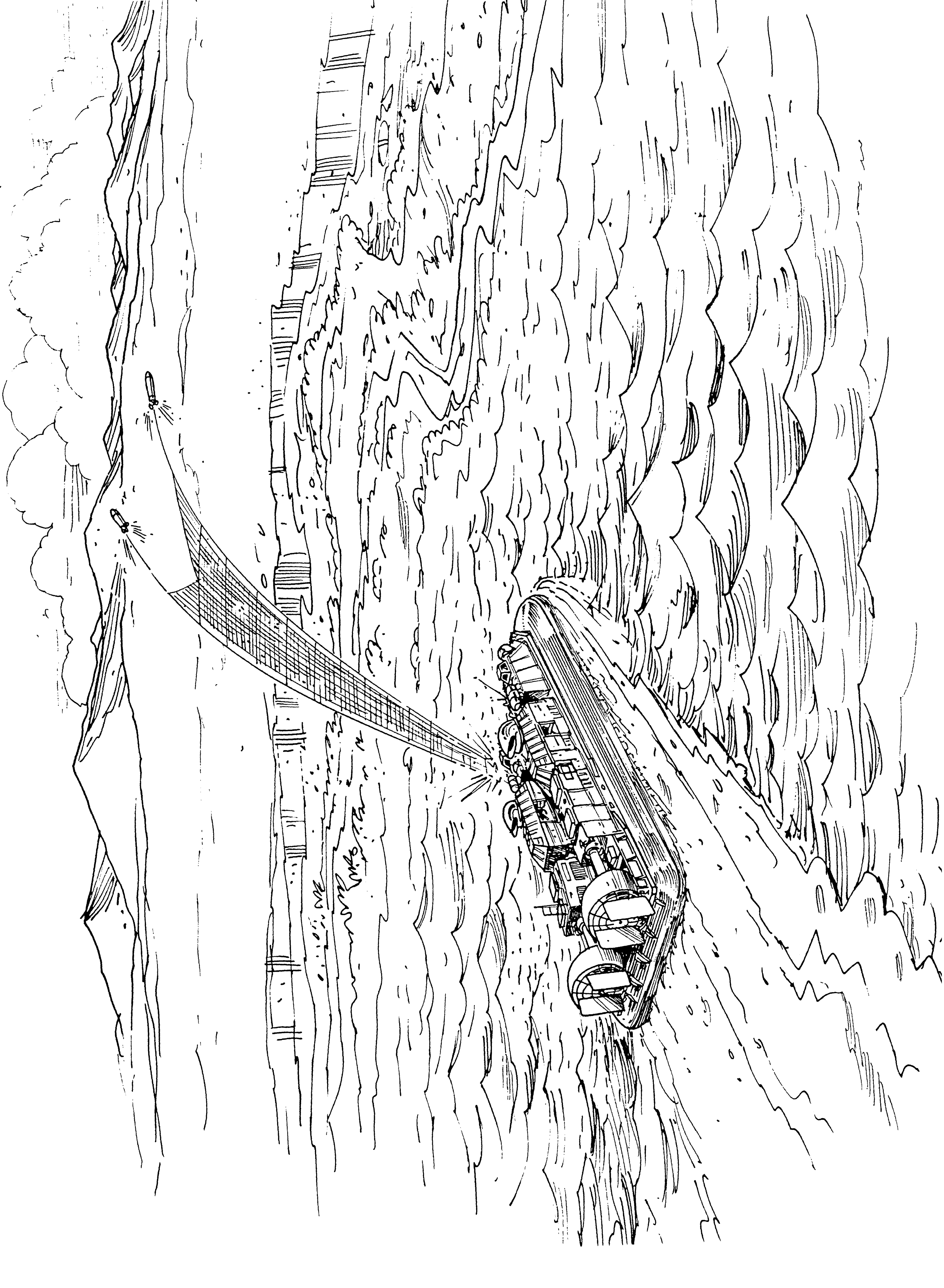
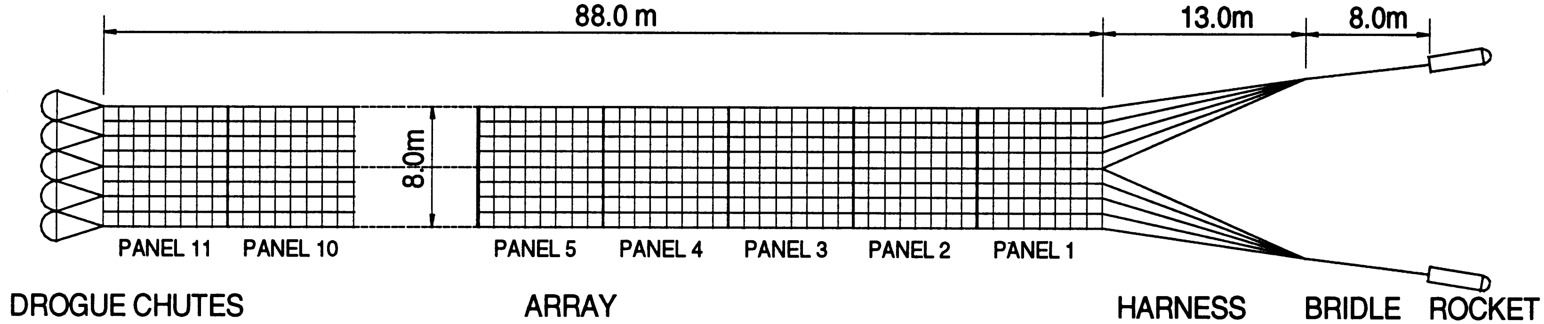


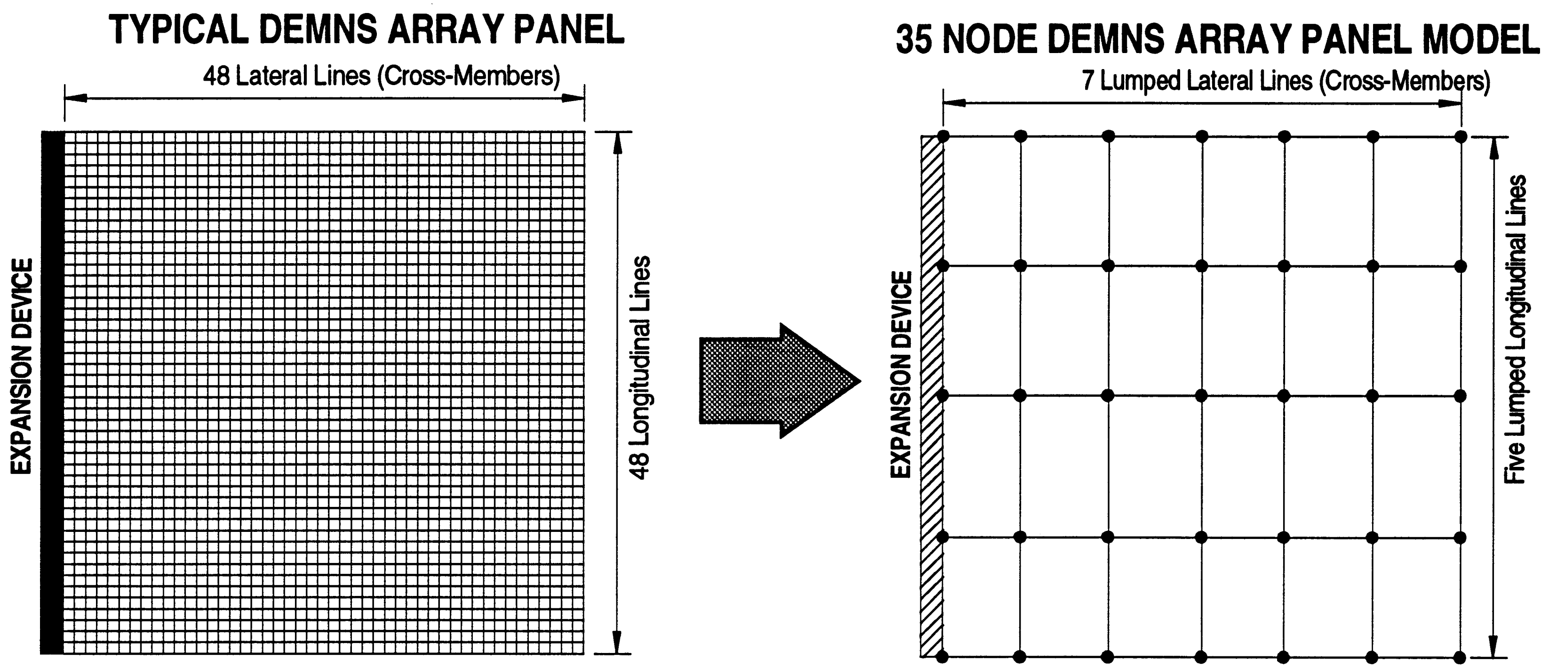
DET Models: Model Component Highlights

General System Configuration (DEMNS shown)

DEMNS SYSTEM CONFIGURATION



Array Panel Discretization Techniques



Array Panel Discretization Techniques

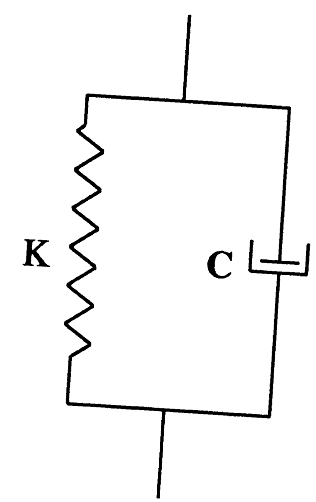
- Lumped Mass Approach
  - Mass of All Array Components (ropes, crimps, fasteners, etc.)
  - Distributed Evenly Over Array
- Network of Mass Nodes
  - Point Masses Used
  - Currently, Near-Zero Rotational Inertias Used
  - Development Effort Underway for True Point Mass Element
- Connected by Viscoelastic Elements
  - Free Lengths Maintain Original Array Dimensions

Array Panel Discretization Techniques: ADAMS Implementation

- PARTs for each mass node (typically 200-300 nodes)
- Center-of-mass MARKER
- Total System Parts Up To 340
  - 2000 + Degrees of Freedom
- Simulation Time Required: >> 1 day

Array Panel Elastic Model

- Material Constitutive Properties Determined Experimentally
- Voight Model
  - Force as a function of strain and strain rate

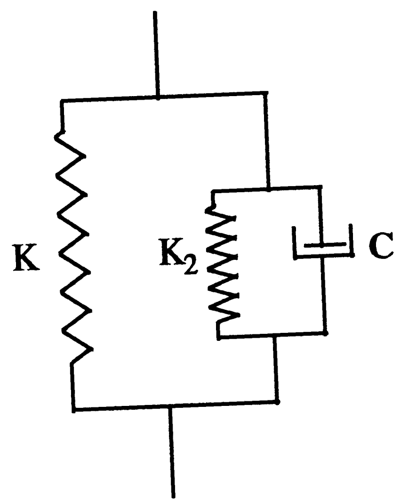


$$F = K\,x + C\,v$$

$$F = K\,(\varepsilon) + C\,(\dot{\varepsilon})$$

Array Panel Elastic Model

- Modified Voight Model
  - Introduces a "dynamic stiffness" along with the static stiffness
  - Fits experimental data better than standard Voight model



$$F = K\,x + K_2\,x + C\,v$$

$$F = K\,(\varepsilon) + K_2\,(\dot{\varepsilon}) + C\,(\dot{\varepsilon})$$

Array Panel Elastic Model: ADAMS Implementation

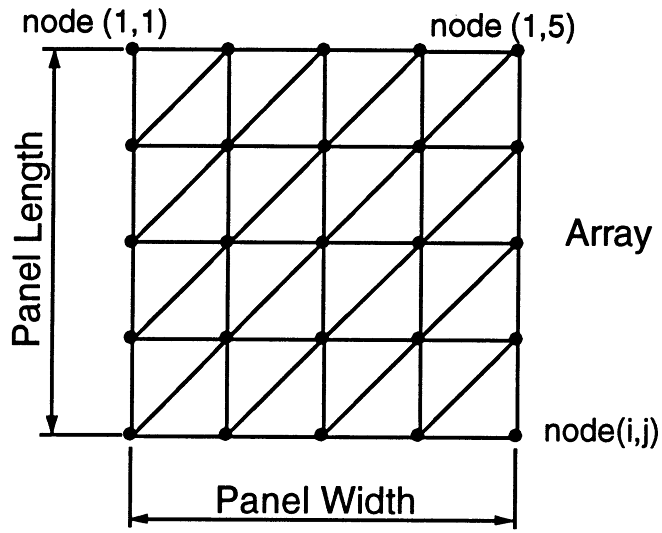
- SFOSUB for force computation
- SPLINEs for material constitutive data
- VFORCE for continuous mass effects
  - Apply artificial "F=ma" type forces
  - Reduce effect of discrete masses

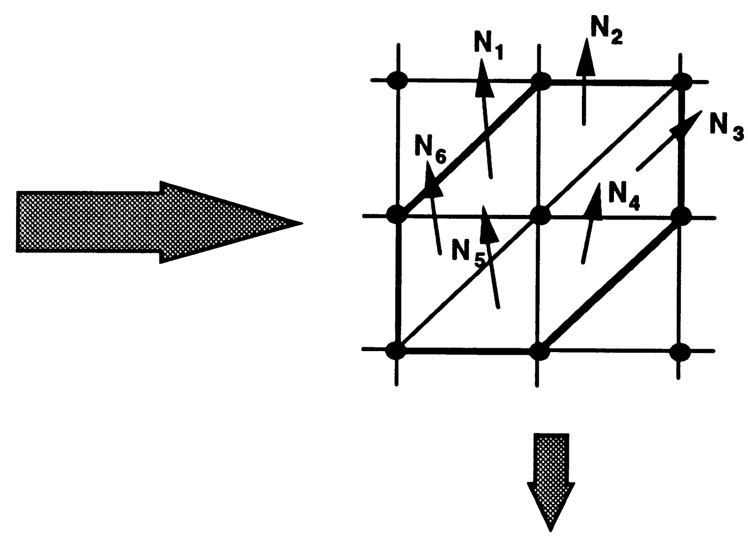
Array Panel Aerodynamic Model

- Aerodynamic Properties Determined Experimentally
- No Previously Existing Research on Net Aerodynamics
- Aerodynamic Behavior is a Function of Deployment State
  - Expansion of Array
  - Influence of Array Components (spars)
- Aerodynamic Coefficients Obtained from Comprehensive Wind Tunnel Testing

$$C_D = \begin{cases} 0° \leq |\alpha| \leq 18°, & C_{D_L} = 0.0087 + 0.0533 \sin 5\alpha \\ 18° \leq |\alpha| \leq 90°, & C_{D_H} = 0.0087 + 0.032 \sin \alpha + 0.071 \sin^2 \alpha \end{cases}$$

Computational Model for Array Panel Aerodynamics





$$F_{drag} = \frac{1}{2}\rho v^2 A C_D$$

$$F_{lift} = \frac{1}{2}\rho v^2 A C_L$$

$$\alpha = \arccos\left(\frac{\vec{N}\bullet\vec{V}_{rel}}{\left|\vec{V}_{rel}\right|}\right) - \frac{\pi}{2}$$

Array Panel Aerodynamic Model: ADAMS Implementation

- VFOSUB for Force Computation
- VFORCE for Wind Vector Definition
  - Wind Velocity Components (Constant or Time-Varying) Defined as VFORCE Components
  - SYSARY used to retrieve "VFORCE" velocity values
- ARRAY for Data Initialization

Rocket Motor Aerodynamic Model

- Analytical Model Based on USAF DATCOM Methodology
- Aerodynamic Properties Determined Experimentally
- Analytical Model Validated and Tuned

$$C_L(\alpha) = \frac{2(K_2 - K_1)S_0}{S_m}\alpha + \frac{2\alpha^2}{S_m}\int_{x_0}^{l_b} \eta\, r_x C_{D_c}\, dx$$

$$C_D(\alpha) = \left(C_{D_0}\right)_B + \frac{2(K_2 - K_1)S_0}{S_m}\alpha^2 + \frac{2\alpha^3}{S_m}\int_{x_0}^{l_b} \eta\, r_x C_{D_c}\, dx$$

$$C_M(\alpha) = (K_2 - K_1)SIN(2\alpha)$$

Rocket Motor Aerodynamic Model: ADAMS Implementation

- GFOSUB for Aerodynamic Force Computation
- GFORCE for Propellant Loss Calculations
  - Apply artificial "F=ma" type forces
  - Account for mass loss as propellant burns

Energy Tracking Tool

- Calculate System Energy Quantities
- Useful for Design and Debugging
- Energy Computed as Time Integral of Power and Velocity
- System Forces Which Contribute to Energy Balance
  - Rocket
  - Stiffness
  - Damping
  - Aerodynamic
  - Gravitational

Energy Tracking Tool:
ADAMS Implementation

- S(V)FOSUB
  - Aerodynamic, Damping and Stiffness Force Computed
  - Dot Product with Velocity Computed
  - Stored in COMMON Block
- DIFSUB
  - Quantities Recieved from S(V)FOSUB through COMMON Block
  - Integration of Power Dot Velocity Computed
- REQSUB
  - SYSFNC called with 'DIF' to access integral quantities
  - Kinetic and Potential Energy Calculated Algebraically
  - Energy Quantities written to Request File

Simulation Results: Comparison To DEMNS Flight Test

Launch Configuration

LAUNCH ANGLE	35°
AZIMUTH ANGLE	6°
MODEL LINES	5
SPARS	10
WIND	no wind
INTEGRATOR	WSTIFF
STEP SIZE LIMIT	0.001
ERROR TOLERANCE	0.001

Simulation Results

COMPONENT	*DEMNS Test 11/4/93*	*ADAMS model*	*% Difference*
Rocket Motor (average)	485.0 ft	482.5 ft	0.5
Front Point of Array	459.0 ft	441.7 ft	–3.8
Rear Point of Array	186.0 ft	193.1 ft	3.8

CONCLUSIONS

- *ADAMS* has become a proven analysis tool for predicting the flight dynamics of Shallow Water Mine Countermeasures systems

- Significant R&D time and cost savings have been realized through the use of *ADAMS* simulations

- Future simulation improvements, such as including the complexities of hydrodynamics and movable launch platforms, are possible with *ADAMS*