Carderock Division,
Naval Surface Warfare Center

Bethesda, Maryland 20084-5000

Progress Report on End-To-End Simulator Development at DTMB

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This report documents current progress by the David Taylor Model Basin (CarderockDiv., NSWC) on the assessment of the Dynamics Technology, Inc. (DTI) End-to-End Simulator that predicts SAR images of ship wakes to determine the suitability of DTI's simulator for predicting the variation in SAR images resulting from variation in ship characteristics. Installation of the DTI End-to-End Simulator at DTMB has been completed and all three test runs supplied by DTI have been successfully run and duplicated. Currently improvements are being made in the code to improve the geometric representation of the ship hull to include realistic hull forms.

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ABSTRACT

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ADMINISTRATIVE INFORMATION

INTRODUCTION

This report documents DTMB's (David Taylor Model Basin, CarderockDiv, NSWC) current progress on the assessment of the Dynamics Technology, Inc. (DTI) End-to-End Simulator that predicts SAR images of ship wakes (SHIPSIM[1]). This assessment was to determine the suitability of DTI's simulator for predicting the variation in SAR images resulting from variation in ship characteristics. In June of 1991, Dynamics Technology, Inc. sent DTMB a magnetic tape containing SHIPSIM. The tape contains source code and data for three test cases. The source code consists of eight FORTRAN computer programs for the simulator, a library of FORTRAN subroutines used by the simulator, and a driver that is used for preparation of input data to the eight programs. The data consist of input data for the eight programs

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and the corresponding output data created by DTI on a Digital VAX computer with a VMS operating system.

DESCRIPTION OF SHIPSIM PROGRAM MODULES

I. DRIVER. This computer program creates a command file to execute the eight modules of the SHIPSIM program sequentially. It also creates the necessary input data files for the eight programs. The reason this driver is necessary is that the modules are pieces of code cut and pasted from previously existing computer codes. There are instances in which the same quantity is read by several of the modules, but the individual modules require the quantity to be in different units of measurement. In addition, there are rotations of coordinate systems from one module to another. In some modules, angles are measured in a clockwise direction and in others, they are measured counter-clockwise.

Input to DRIVER is entered in response to menu queries. The major input parameters are divided into groups as shown in Table 1. Each group corresponds to a menu item in the main program. The user is given an opportunity to read a data file containing previous setup parameters and thus make only the minimal modifications necessary, through the menus, to create new input data files corresponding to a different set of parameters.

DRIVER, as it was supplied by DTI, writes a VAX/VMS command file, which can be used to execute the following eight modules on a VMS computer.

II. TSKWAVE. This module calculates the Kelvin wake data required for the two-scale radar backscatter calculations. The ship is assumed to be characterized completely by its length, beam, and draft to which a mathematically defined parabolic-shaped hull (the Wigley hull form) is fitted. Other required input data are the speed of the ship and a rectangular grid of points in the wake of the ship on which the Kelvin wake data are calculated.

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Table 1. Major input parameters for DRIVER.

Ship Parameters	SAR Parameters	
length	wavelength	range resolution
beam	polarization	altitude
draft	look direction	heading
speed	incidence angle	velocity
heading	azimuthal resolution	delta velocity
distance aft to scene center		
Ambient Parameters	Image Parameters	
wind speed	# pixels in two directions	
wind direction	dimensions of each pixel	
swell heading		
peak power wave number		
half width wave number	Other Parameters	
RMS height	radial offset	
angular spread	azimuthal offset	

The Kelvin wake data computed by this module are grouped into separate files each containing exclusively short, intermediate, or long wavelength data. The data stored in the long wavelength data files are the free-surface elevation, the velocities in the radar look direction, the free-surface slopes, and the accelerations in the radar look direction due to the long wave portion of the spectrum. Intermediate wavelength data files contain mean free-surface slopes, mean velocities and accelerations in the radar look direction, the free-surface slope variances, and the variance of the velocities in the radar look direction due to the intermediate wave portion of the spectrum. The short wavelength files include only the square of the amplitude of the free-surface waves due to the short wave portion of the wave spectrum.

III. SWLONGSS. This module adds long wind-wave effects to the long ship-wave data. The addition is linear. Radar backscatter cross-section due to the long waves is calculated.

IV. SWINTSS. This module calculates modulations in the radar cross section due to the superposition of the stationary Kelvin waves and the

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wind waves in the intermediate and short wave portions of the wave spectrum.

V. TURBSS. This module computes the modulation of the ambient action of Bragg-sized waves due to ship wake turbulence. The results are computed on a grid that is different from the grid used by all of the other modules.

VI. IMROTATE. This module interpolates the data computed by TURBSS to the grid used by all the other modules in SHIPSIM.

VII. IMADD. This module combines image intensity files.

VIII. IMFOR32. This module assembles the field of image intensities given the scene data.

IX. SPECKLE. This module adds speckle noise to the calculated image intensity data. This module produces the result, that is, data that can be visualized with the aid of gray-scale plots.

INSTALLATION OF SHIPSIM ON DTMB COMPUTERS

To get the code running on Apollo computers at DTMB, some code changes were required to account for differences between the FORTRAN compiler on the Apollo and the FORTRAN compiler on the VAX. First, several statements required an extra pair of parentheses. Another difficulty occurred because the VAX compiler creates object code that stores all variables statically and sets them to zero. If this is done on an Apollo, all optimization by the FORTRAN compiler is disabled. FORTRAN DATA statements were added to several subroutines for those few variables that actually need to be stored statically, so that the Apollo FORTRAN compiler could be used to optimize the resulting object code. (Statically stored variables retain their value between calls to a subroutine; dynamically stored variables do not. If a subroutine assumes that a variable will be defined as it was defined in the previous call to the subroutine, then that variable must be stored statically.

Otherwise, the computer will be computing with an unknown quantity stored in the memory register for that variable with unpredictable results.) The alternative is to have a computer program that executes more slowly.

Replacements were required for several machine-dependent subroutines. These subroutines included the VAX random number generator and VAX system routines to allocate and deallocate storage dynamically. The random number generator has been replaced with a portable subroutine written in FORTRAN. The subroutines for storage allocation and deallocation were replaced by calls to Apollo system subroutines. These Apollo system routines can also be replaced by portable routines written in C. However, there is some question as to whether storage is released (as it should be) on the Apollo when the relevant C routine is called. Hence, it was decided to use the Apollo system routines.

Comparative runs had to be made on a VAX computer to track down and fix the causes of discrepancies in results for the three test cases. It happens that the Apollo FORTRAN compiler produces faulty object codes for several subroutines on some of the Apollo computers. This was remedied by compiling those subroutines at a lower level of optimization. The resulting code is slower, but it gives the correct results. In doing the comparative runs, the VAX random number generator was emulated on the Apollo by reading in the output from the VAX random number generator. The random numbers had been previously computed on a VAX and stored in a file on the Apollo. The Apollo version of SHIPSIM now produces results that are nearly identical to the results from the VAX if the VAX random number generator is emulated on the Apollo. There are differences due to rounding errors, but these are to be expected.

The original DRIVER produced a VAX command file suitable for running with a VMS operating system. The Apollo does not have the VMS operating system, so the command file generated by DRIVER had to be replaced with another one suitable for an operating system on the Apollo. Hence, a few of the subroutines in DRIVER that write the commands in the command file were changed to write commands in the Korn shell command programming language. The Korn shell is a part of UNIX software, which

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seems to be available on an increasing number of computers.

COMPUTATIONAL RESULTS

Results from the three test cases supplied by DTI are presented. In each of the three cases the ship is a parabolic Wigley hull form of length 270 m, beam 33 m, and draft 12 m. The SAR is traveling due east at a speed of 120 m/s (233 kn) and an altitude of 3000 m. It is transmitting and receiving vertically polarized waves of wavelength 0.235 m (L-band) with an incidence angle of 30 degrees. The wind is blowing from the direction 225 degrees clockwise from north at a speed of 4 m/s (7.77 kn). The ship's heading and speed and the SAR look direction are varied among the three cases. The distance between the center of the scene and the center of the ship is also varied slightly.

Two gray-scale plots and a corresponding schematic drawing are presented for each of the three cases. One gray-scale plot corresponds to the results computed by DTI on a Digital VAX computer, and the other corresponds to the results computed on an Apollo micro computer at DTMB where the VAX random number generator has been emulated. Each of the plots corresponds to an array of 300 by 300 square pixels, each 6 m square. Thus the physical size of the plots is 1800 m in the ground range and azimuthal directions.

In all the gray-scale plots it is assumed that the SAR look direction is downward on the page and that the SAR is traveling toward the right side of the page. Compass directions are indicated on the schematic sketches.

For Case 1, shown in Figures 1 and 2, the SAR is traveling east and looking toward its left (north). The wind is blowing from the southwest. The ship is heading due west at 8.13 m/s (15.8 kn). There is a distance of 1141 m between the center of the ship and the center of the scene. This places the ship immediately to the left of the gray-scale plot. This scenario is depicted by the schematic presented in Figure 3. The two gray-scale plots corresponding to the results from the Apollo and the VAX are indistinguishable.

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Similar good comparisons can be seen in the gray-scale plots for the second and third cases, shown in Figures 4 and 5, and Figures 7 and 8 respectively. The only difference between Case 1 and Case 2, Figure 6, is that the ship's heading is different and the distance between the center of the scene and the center of the ship is 1361 m instead of 1141 m. In Case 3, Figure 9, the SAR is again traveling to the right (east), but it is looking to its right (south). Otherwise, the parameters are the same in Cases 2 and 3.

AREAS FOR IMPROVEMENT -- KELVIN WAKE

In SHIPSIM, a ship is completely characterized by its velocity and its length, beam, and draft to which a parabolic hull form is fitted. A more accurate geometric representation of the ship hull should produce Kelvin wake predictions that more accurately reflect details of the hull form. The use of the parabolic Wigley hull allows the Kelvin wave pattern behind the ship hull to be decomposed into the sum of four waves: a bow transverse wave, a bow diverging wave, a stern transverse wave, and a stern diverging wave. With a more accurate geometric representation of the hull, the wave pattern will become more complicated to calculate.

The strategy for improving the Kelvin wake computations in SHIPSIM is a process involving several steps. First, we need to identify what aspects of the Kelvin wake are being computed. Then it becomes important to know how these Kelvin wake data are used in subsequent modules. With this information, it will be possible to determine what existing Kelvin wake codes can replace parts or all of the modules that presently compute the Kelvin wake.

AREAS FOR IMPROVEMENT -- TURBULENT WAKE

The turbulent wake model for SHIPSIM is found in module TURBSS. In TURBSS, a ship is characterized by only its velocity and beam. These two parameters are used to estimate the width and intensity of the turbulent wake. A more realistic method for including wake characteristics is required

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in order to relate SAR image characteristics to hull form; for example, the momentum of the trailing wave field and the total drag of the ship should be accounted for. Other ship parameters that, if included, would enhance the calculation are the velocity at wake centerline, the turbulent kinetic energy in the wake, and the propeller torque and configuration.

In addition to the lack of detail in the characterization of a ship, there are two other simplifications in TURBSS that result in less accurate predictions of SAR images. Currently, the exponents for the asymptotic behavior of the wake are derived from measurements of a self-propelled submerged body. A self-propelled submerged body ideally produces a momentumless wake since the momentum defect caused by the drag of the body is exactly canceled by the momentum surplus provided by the propeller. In the case of a surface ship, however, there is a flux of momentum away from the ship in the form of the Kelvin wake which is balanced by a momentum surplus in the viscous wake. That is, the propeller of a surface ship must overcome both the momentum defect caused by the viscous drag of the ship and the momentum loss caused by the wave drag. This has an important implication to SAR imagery prediction–wakes containing momentum decay more slowly and spread more rapidly than momentumless wakes. For this reason, the asymptotic wake model is a primary target for improvement.

The second simplification is in the dissipation and growth of Bragg waves. DTI has restricted the minimum value to which Bragg waves may be damped by turbulence and wave breaking to a fixed fraction of the ambient value. This restriction is probably required due to an inaccuracy in DTI's assumptions about wind growth rates and breaking of the Bragg waves rather than an improper modeling of the effect of turbulent damping. The model that DTI uses for wind growth rate and wave breaking dissipation rate is based on investigations of ambient wave spectra, rather than the range of wavelengths and wave heights found in a ship wave spectrum.

The strategy for improving the turbulent wake computations in SHIPSIM will include an investigation into the effect of the simplifications made in the turbulent wake on the SAR images predicted by the model. Then a determination will be made of the detail that can be reasonably in-

cluded in an improved model. With this information, it will be possible to replace all or parts of TURBSS with code that will more accurately reflect ship characteristics in predicted SAR images.

CONCLUSIONS

Installation of the DTI End-to-End Simulator at DTMB has been completed and all three test runs supplied by DTI have been successfully run and duplicated. Currently improvements are being made in the code to improve the geometric representation of the ship hull to include realistic hull forms, thus improving the computed Kelvin wake. This will, in turn, provide more accurate input data to the SAR images calculated in the other modules of the code. In addition to the Kelvin wake, the turbulent wake modeling aspect of the code will be improved by including a momentum representation of the turbulence wake, relating the initial turbulent wake parameters to hull form and ship operating conditions, and by allowing for realistic wind growth and Bragg wave damping.

After the modifications to the code have been made, the computed images will be compared with data from the 1989 ONR Ship Wake Experiment and an assessment of correlation will be made.

tskspkl.vax (300 by 300 at 6 by 6 m/p)

| 0.7 | 0.775 | 0.85 | 0.925 | 1 | 1.075 | 1.15 | 1.225 | 1.3 |
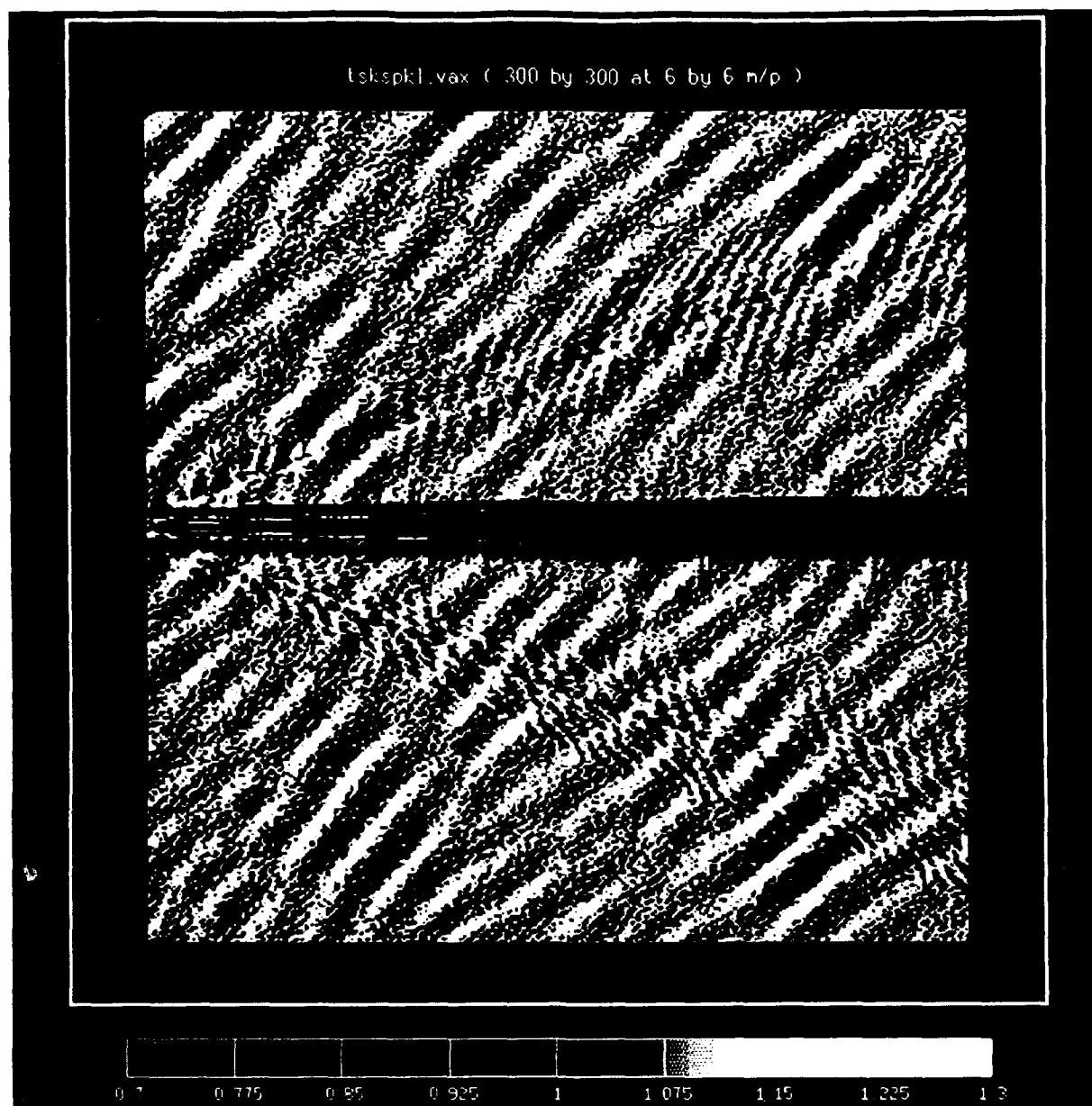
CASE 1 — VAX (DTI)

ship parameters
L = 270 m
B = 33 m
D = 12 m
U = 8.12 m/s (15.77 k)
heading = 270°
distance aft = 1141 m

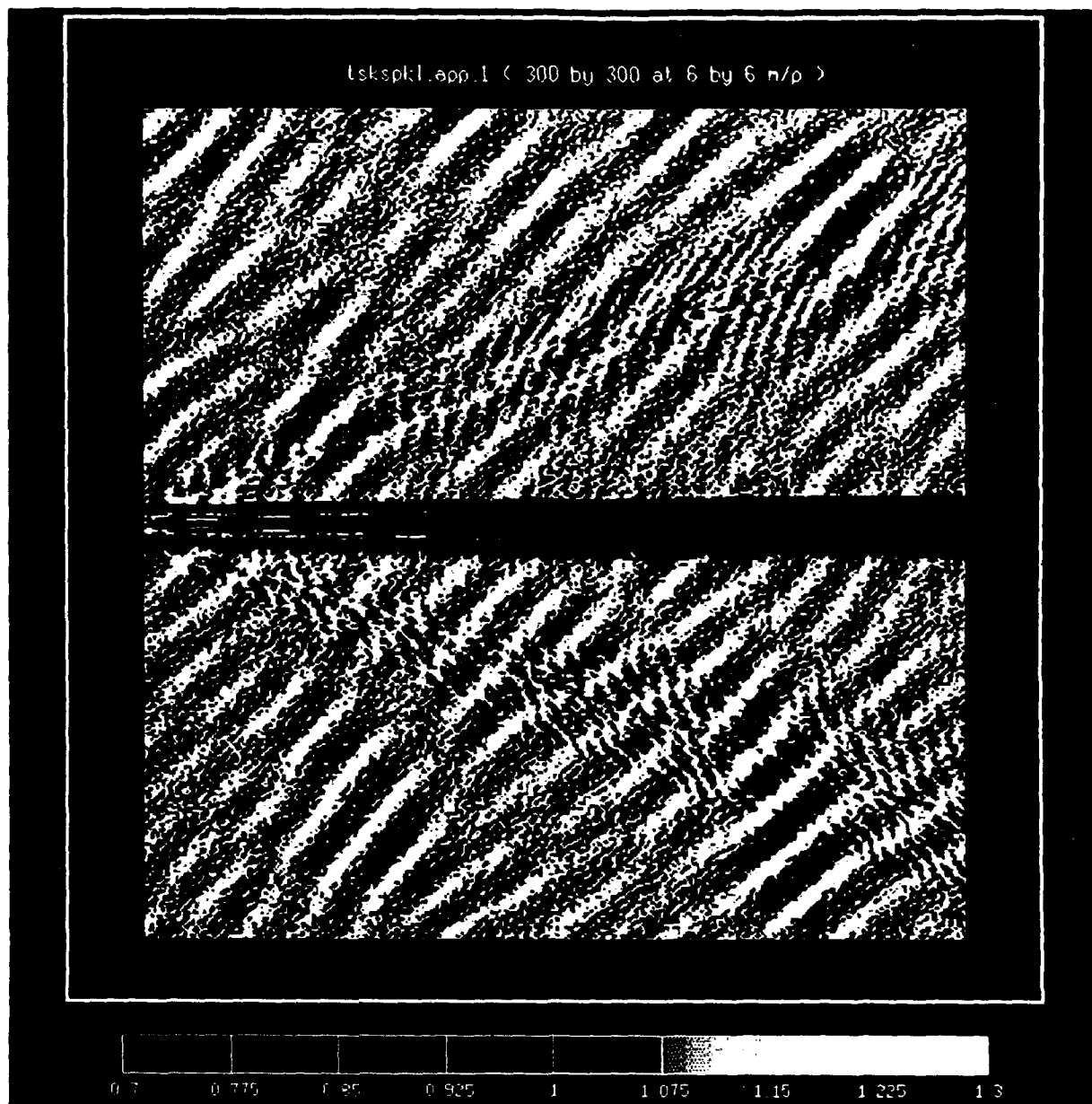| |
| :---: |
| pixel size = 6 m x 6 m |
| radial offset = 835 m |
| az. offset = -897 m |

ambient parameters
wind speed = 4 m/s (7.77 k)
direction = 225°
swell heading = 45°
peak power wavenumber = 0.06 rad/m
half width wavelength = 0.01 rad/m
RMS height = 0.305 m
angular spread = 35°

SAR parameters
wavelength = .235 m
altitude = 3000 m
incidence angle = 30°
vv polarization
velocity = 120 m/s
heading = 90°
delta velocity = 0
resolution = 1 m x 1 m
look direction = left

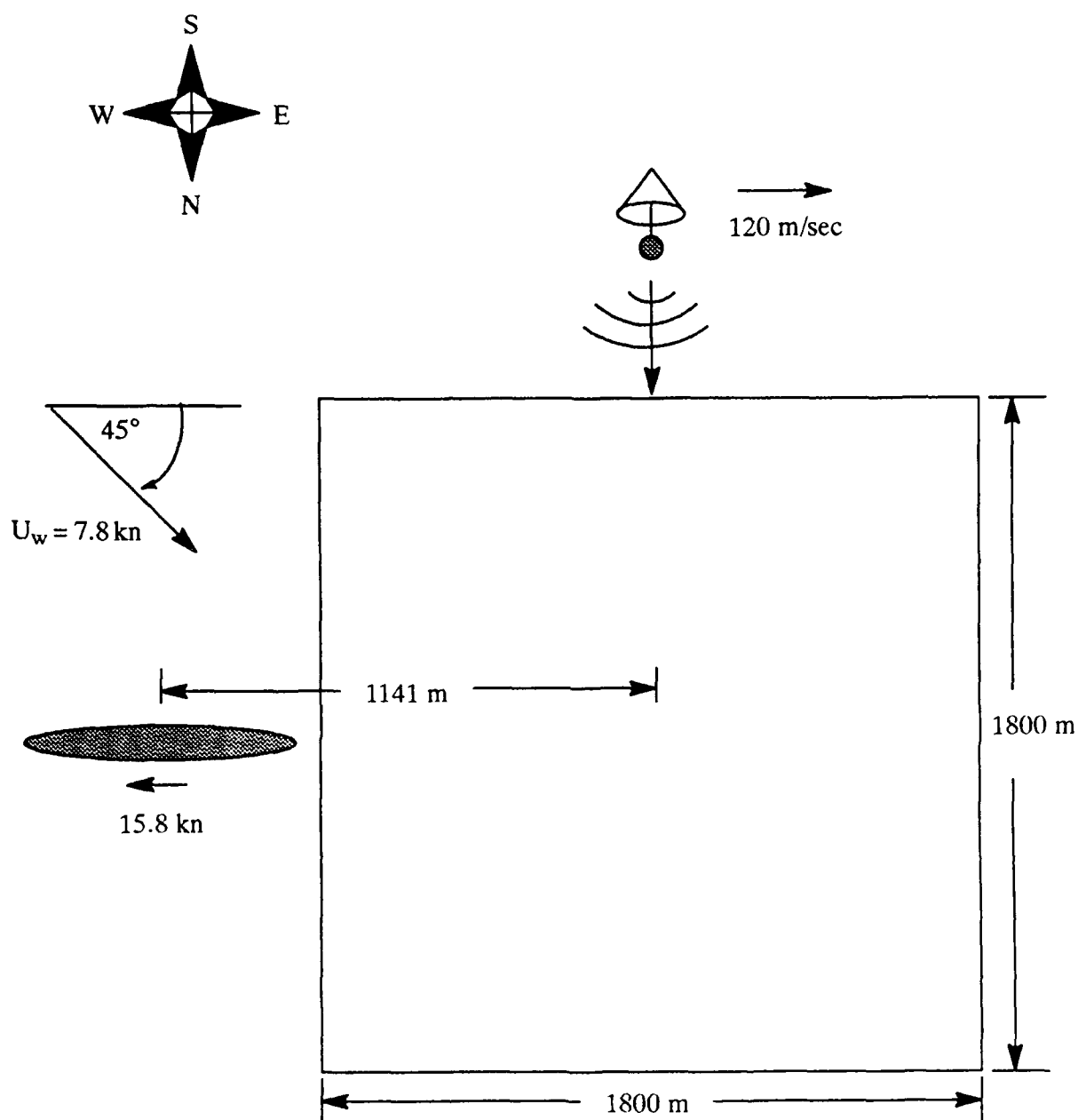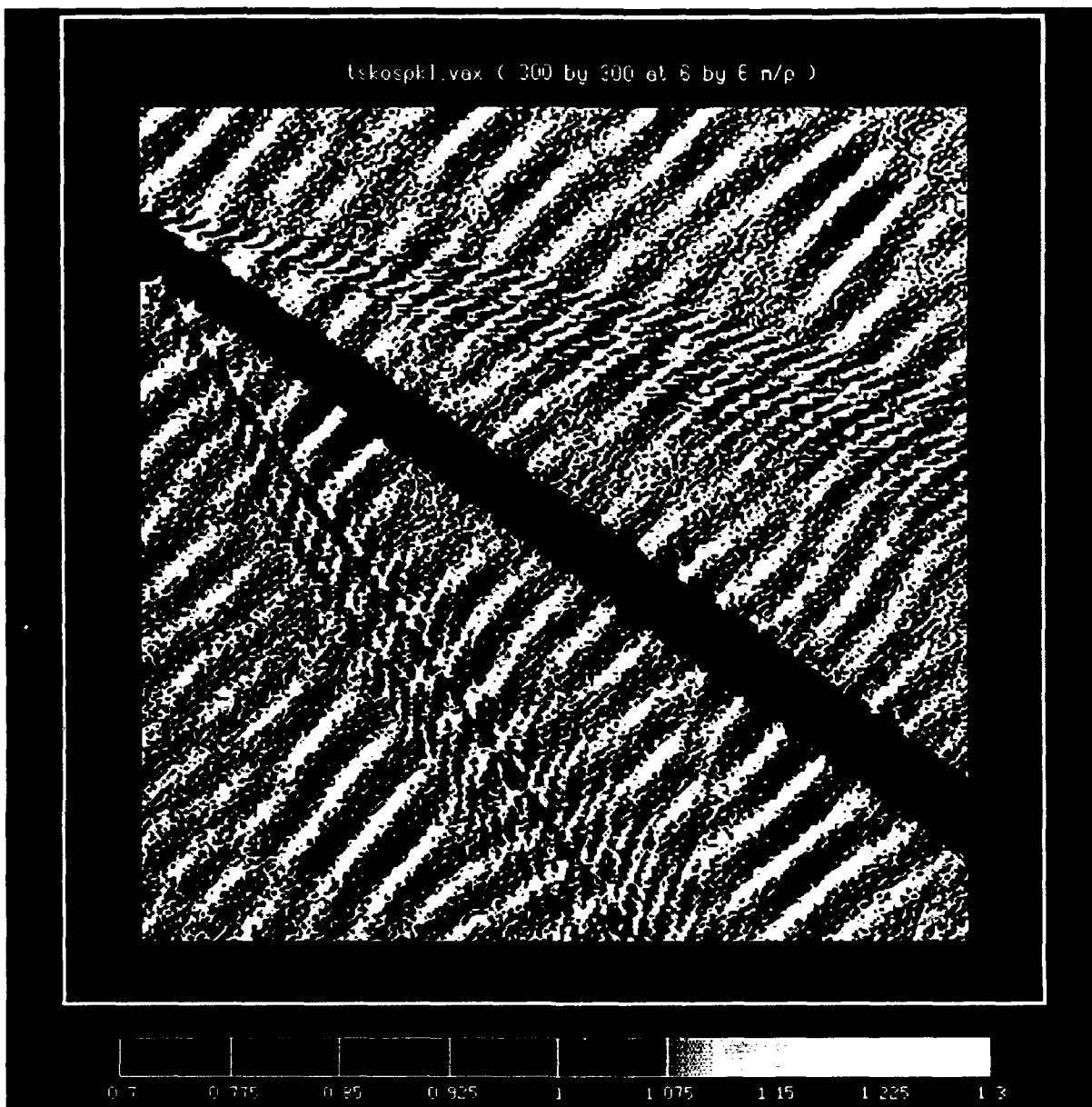**Fig. 1.** Simulated SAR image for Case 1 computed at DTI.

CASE 1 — APOLLO (DTMB)

ship parameters	ambient parameters	SAR parameters
L = 270 m		wavelength = .235 m
B = 33 m	wind speed = 4 m/s (7.77 k)	altitude = 3000 m
D = 12 m	direction = 225°	incidence angle = 30°
U = 8.12 m/s (15.77 k)	swell heading = 45°	vv polarization
heading = 270°	peak power wavenumber = 0.06 rad/m	velocity = 120 m/s
distance aft = 1141 m	half width wavelength = 0.01 rad/m	heading = 90°
	RMS height = 0.305 m	delta velocity = 0
pixel size = 6 m x 6 m	angular spread = 35 °	resolution = 1 m x 1 m
radial offset = 835 m		look direction = left
az. offset = -897 m		

Fig. 2. Simulated SAR image for Case 1 computed at DTMB.

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Fig. 3. Schematic drawing of the configuration in Case 1.

Fig. 4. Simulated SAR image for Case 2 computed at DTI.

CASE 2 — VAX (DTI)

ship parameters
L = 270 m
B = 33 m
D = 12 m
U = 8.12 m/s (15.77 k)
heading = 235°
distance aft = 1361 m

pixel size = 6 m x 6 m
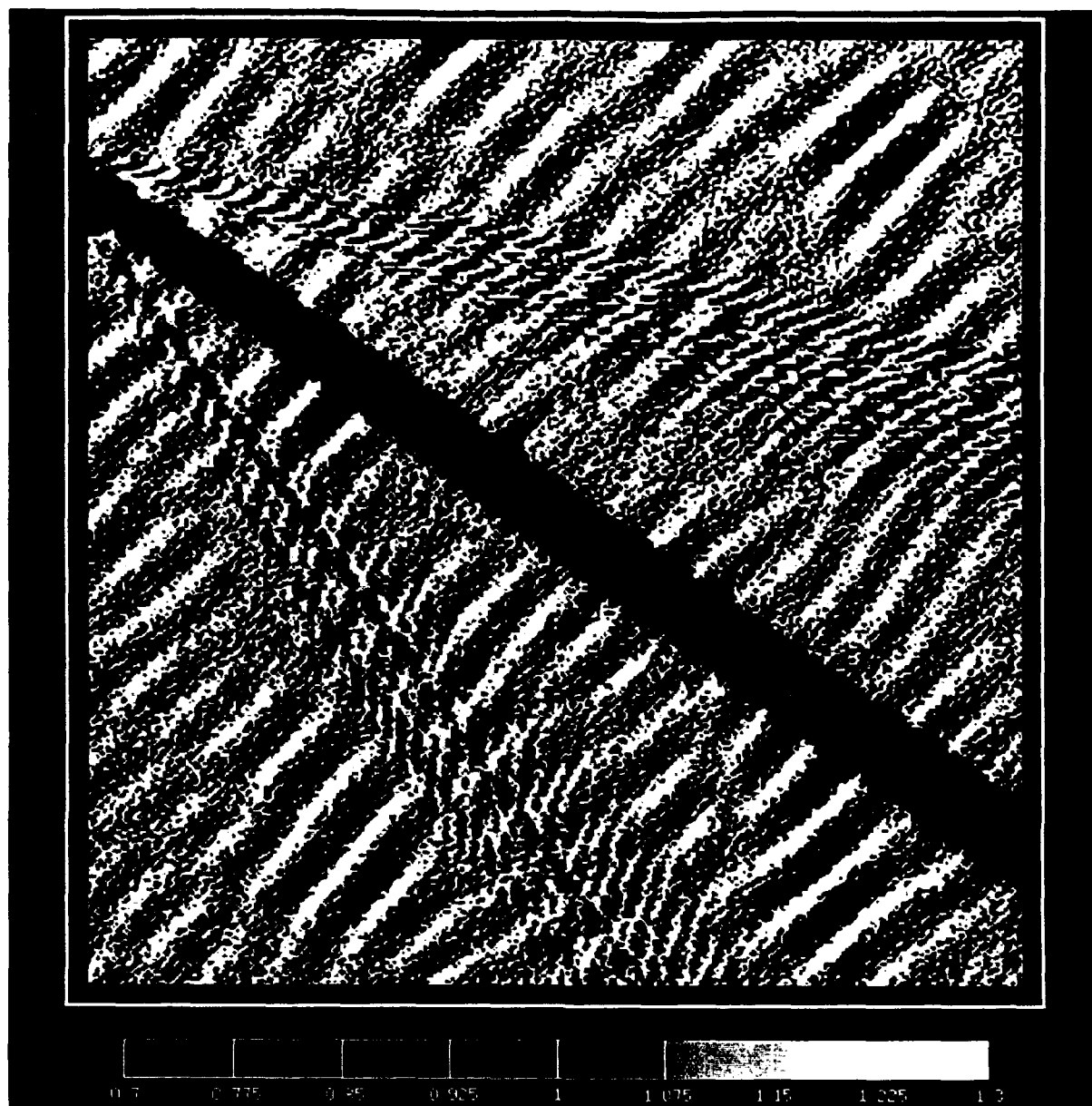radial offset = 835 m
az. offset = -897 m

ambient parameters
wind speed = 4 m/s (7.77 k)
direction = 225°
swell heading = 45°
peak power wavenumber = 0.06 rad/m
half width wavelength = 0.01 rad/m
RMS height = 0.305 m
angular spread = 35°

SAR parameters
wavelength = .235 m
altitude = 3000 m
incidence angle = 30°
vv polarization
velocity = 120 m/s
heading = 90°
delta velocity = 0
resolution = 1 m x 1 m
look direction = left

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CASE 2 — APOLLO (DTMB)

ship parameters	ambient parameters	SAR parameters
L = 270 m		wavelength = .235 m
B = 33 m	wind speed = 4 m/s (7.77 k)	altitude = 3000 m
D = 12 m	direction = 225°	incidence angle = 30°
U = 8.12 m/s (15.77 k)	swell heading = 45°	vv polarization
heading = 235°	peak power wavenumber = 0.06 rad/m	velocity = 120 m/s
distance aft = 1361 m	half width wavelength = 0.01 rad/m	heading = 90°
	RMS height = 0.305 m	delta velocity = 0
pixel size = 6 m x 6 m	angular spread = 35°	resolution = 1 m x 1 m
radial offset = 835 m		look direction = left
az. offset = -897 m		

Fig. 5. Simulated SAR image for Case 2 computed at DTMB.

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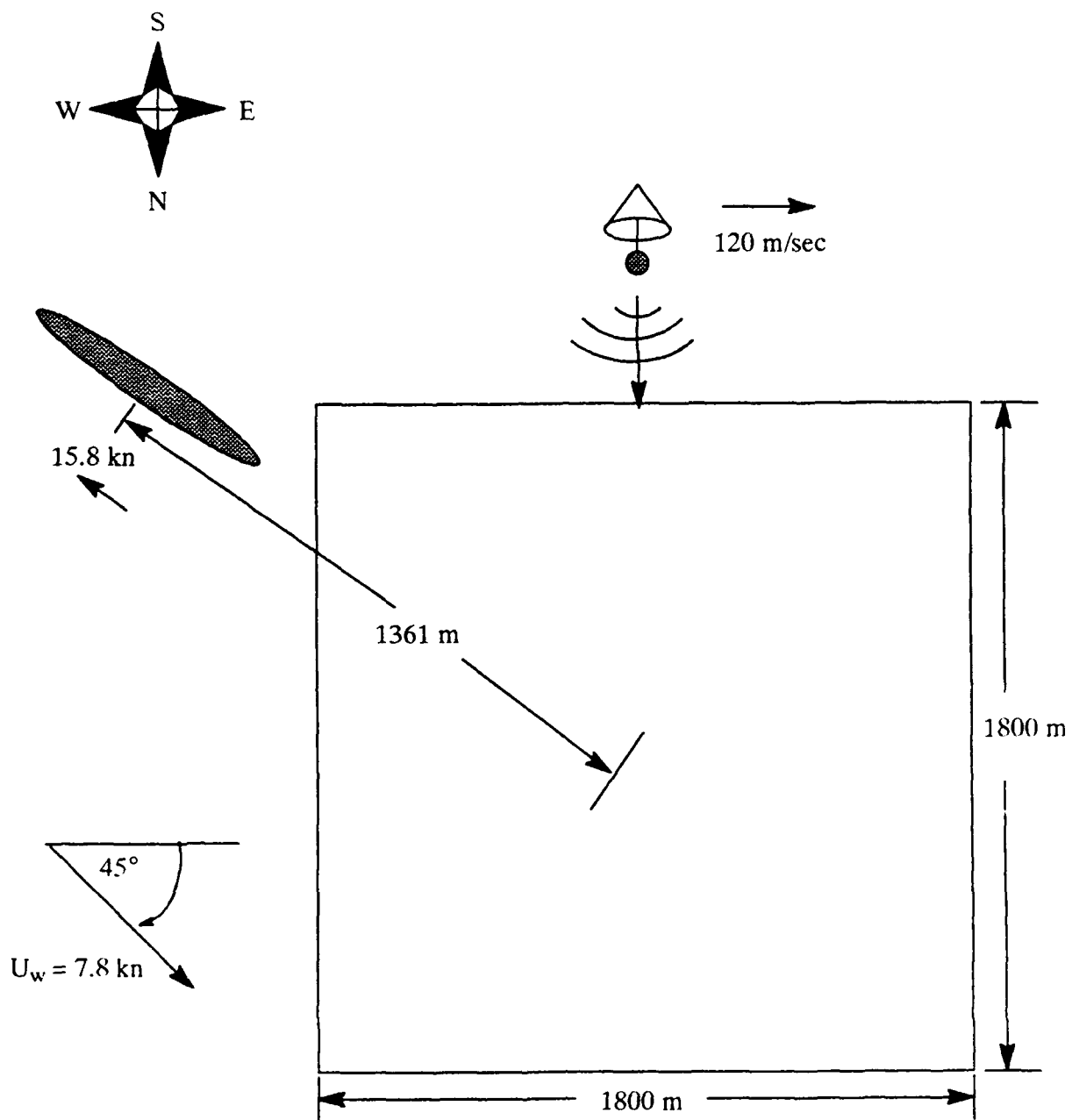
Fig. 6. Schematic drawing of the configuration in Case 2.

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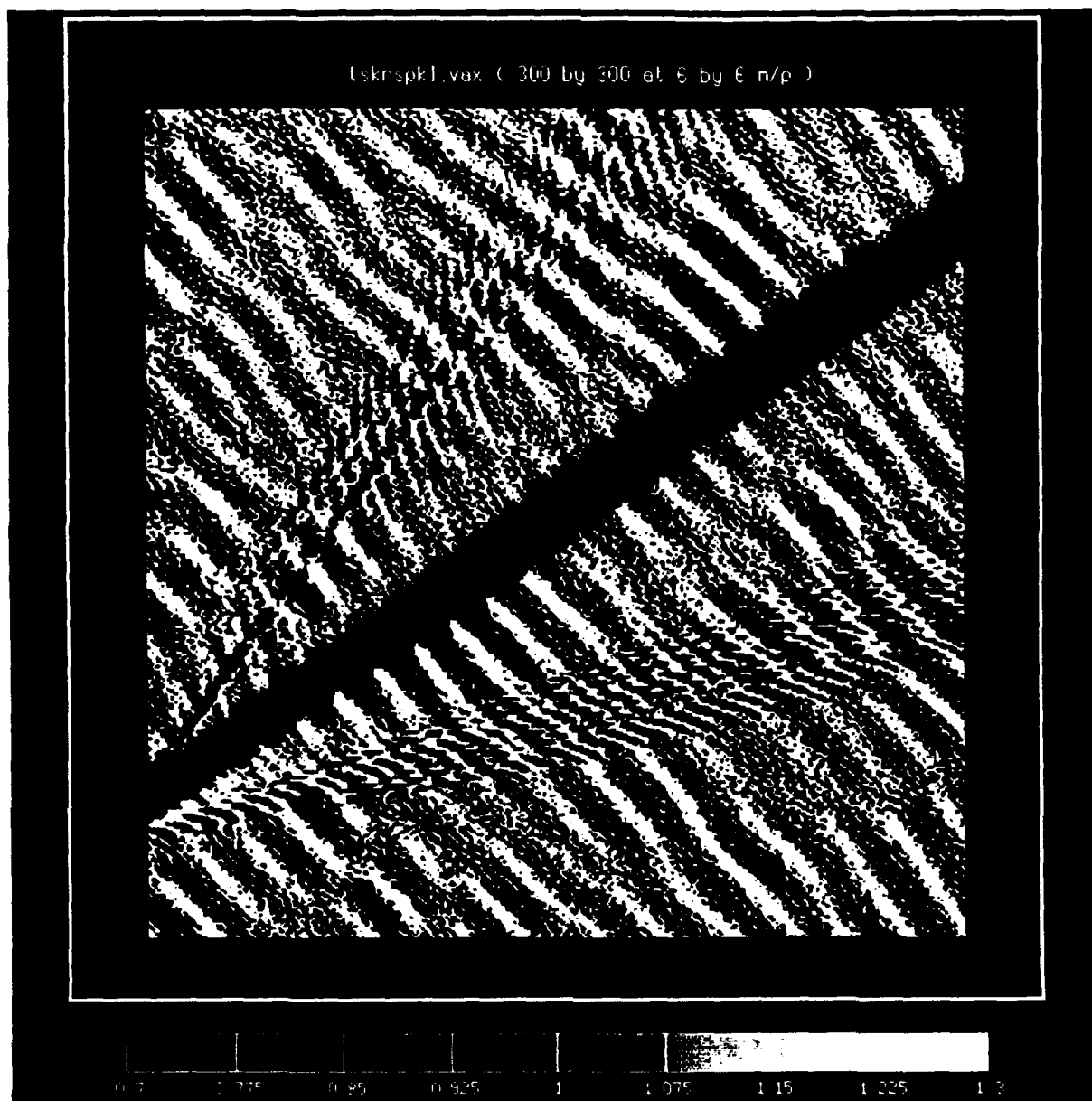
CASE 3 — VAX (DTI)

ship parameters	ambient parameters	SAR parameters
L = 270 m		wavelength = .235 m
B = 33 m	wind speed = 4 m/s (7.77 k)	altitude = 3000 m
D = 12 m	direction = 225°	incidence angle = 30°
U = 8.12 m/s (15.77 k)	swell heading = 45°	vv polarization
heading = 235°	peak power wavenumber = 0.06 rad/m	velocity = 120 m/s
distance aft = 1361 m	half width wavelength = 0.01 rad/m	heading = 90°
	RMS height = 0.305 m	delta velocity = 0
pixel size = 6 m x 6 m	angular spread = 35°	resolution = 1 m x 1 m
radial offset = 835 m		look direction = right
az. offset = -897 m		

Fig. 7. Simulated SAR image for Case 3 computed at DTI.

CASE 3 — APOLLO (DTMB)

ship parameters	ambient parameters	SAR parameters
L = 270 m		wavelength = .235 m
B = 33 m	wind speed = 4 m/s (7.77 k)	altitude = 3000 m
D = 12 m	direction = 225°	incidence angle = 30°
U = 8.12 m/s (15.77 k)	swell heading = 45°	vv polarization
heading = 235°	peak power wavenumber = 0.06 rad/m	velocity = 120 m/s
distance aft = 1361 m	half width wavelength = 0.01 rad/m	heading = 90°
	RMS height = 0.305 m	delta velocity = 0
pixel size = 6 m x 6 m	angular spread = 35°	resolution = 1 m x 1 m
radial offset = 835 m		look direction = right
az. offset = -897 m		

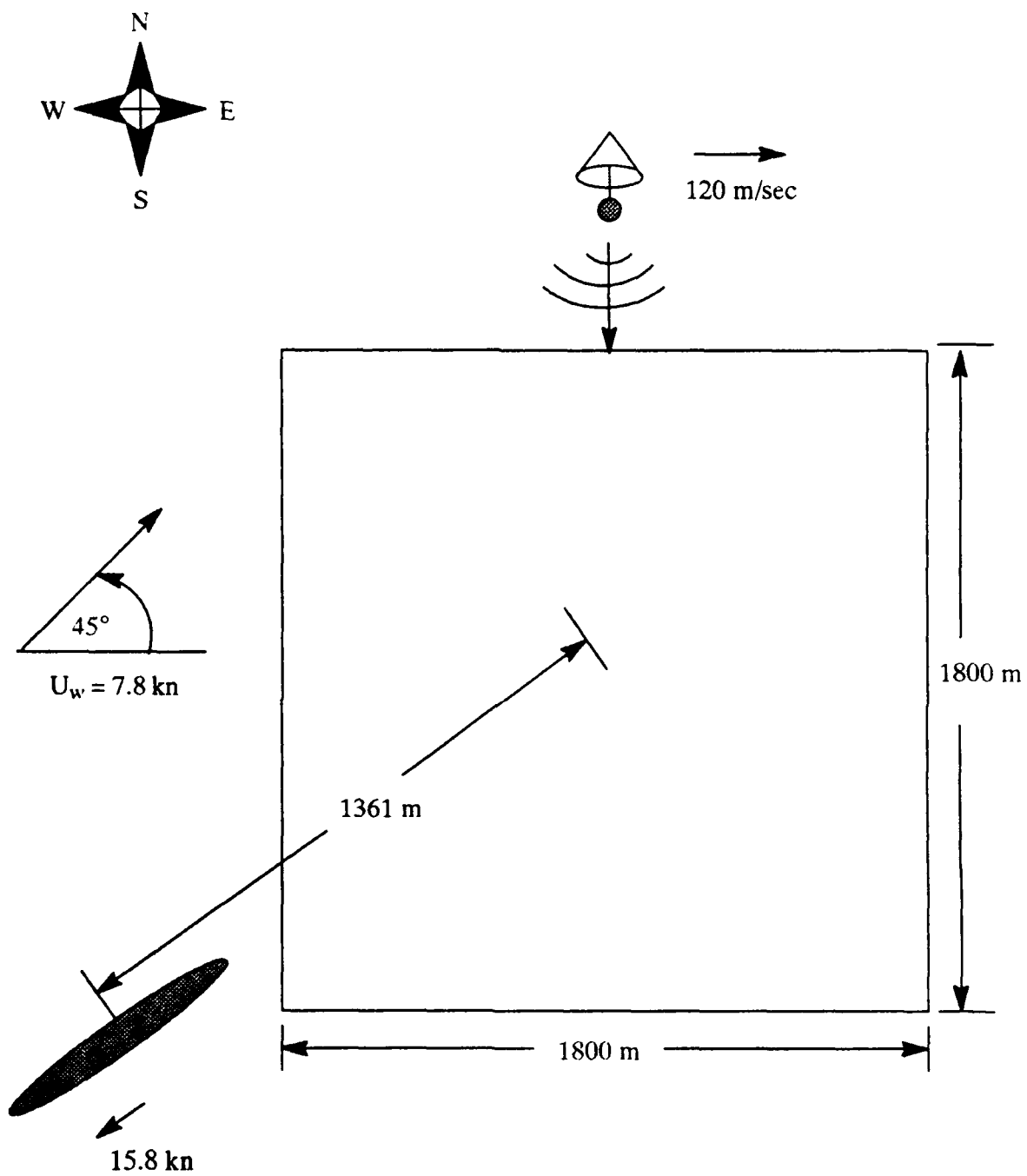**Fig. 8.** Simulated SAR image for Case 3 computed at DTMB.

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Fig. 9. Schematic drawing of the configuration in Case 3.

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1. McLaren, W., P.S. Jang, D. Lai, R. Sharman, "Development of an End-to-End Simulator for Predicting the SAR Imagery of Ship Wakes," Dynamics Technology Inc. Report DT-8658-09 (Nov 1987).

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